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Infants' perception of the physical and social world: Early sensitivity to spatial and interpersonal relations

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Abstract: The area of research investigated in the studies of the research papers presented in this work is twofold. First, infants' ability to process spatial relational information in objects and faces was examined in research paper 1 to 6. Second, infants' sensitivity to socialinteractional factors in dyadic and triadic exchanges were explored in research paper 7 to 10. Well established infancy methods such as the habituation-novelty preference technique or the still-face paradigm were employed to investigate these issues. The results regarding object perception suggest that infants are sensitive to many of the same object properties that adults use to derive important ecological information such as object structure, spatial layout, and figure-ground boundaries. Moreover, infants are sensitive to facial information that is thought to underlie expert face processing by adult humans. While sensitivity to spatial relational information in objects and faces is operational early in life and follows adult patterns in many regards, perceptual development within infancy and between infancy and adulthood is not rule out. The research investigating very young infants' behavior in dyadic interactions reveals that infants are not perturbed by violations of natural face-to-face exchanges until they are about 1.5 months of age. The findings further suggest that infants are especially attuned to the social partner's interactive face. Once infants open the dyadic interactions to incorporate objects and events, they socially share experiences about an entity in the environment. Actively engaging in triadic interactions is considered a milestone in social and cognitive development. It sets the premise for cultural learning. We demonstrated that infants are as likely to engage in triadic interactions with an adult stranger than with a familiar caregiver, and that processing and learning about objects within this social context is sensitive to the social-interactional factors that prevail.

INFANTS' PERCEPTION OF THE PHYSICAL AND SOCIAL WORLD: EARLY SENSITIVITY TO SPATIAL AND INTERPERSONAL RELATIONS

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vorgelegt von
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Included Research Papers

1. Bhatt, R. S. & Bertin, E. (2001). Pictorial cues and three-dimensional information processing in early infancy. *Journal of Experimental Child Psychology, 80,* 315-332.

2. Bertin, E., & Bhatt, R. S. (2006). Three-month-olds' sensitivity to orientation cues in the three-dimensional depth plane. *Journal of Experimental Child Psychology, 93,* 45-62.

3. Bhatt, S. R., Hayden, A., Reed, A., Bertin, E., & Joseph, J. (2006). Infants' perception of information along object boundaries: Concavities versus convexities. *Journal of Experimental Child Psychology, 94,* 91-113.

4. Bertin, E., & Bhatt, R. S. (2001). Figural goodness, stimulus heterogeneity, similarity and object segregation in infancy. *Developmental Science, 4*, 423-432.

5. Bertin, E., & Bhatt, R. S. (2004). The Thatcher illusion and face processing in infancy. *Developmental Science, 7,* 431-436.

6. Bhatt, R. S., Bertin, E., Hayden, A., & Reed, A. (2005). Face processing in infancy: Developmental changes in the use of different kinds of relational information. *Child Development, 76,* 169-181.

7. Bertin, E., & Striano, T. (2006). The still-face response in newborn, 1.5-, and 3-month-old infants. *Infant Behavior and Development, 29,* 294-297.

8. Striano, T., & Bertin, E. (2004). Contribution of facial and vocal cues in the still-face response of 4-month-old infants. *Infant Behavior and Development, 27,* 499-508.

9. Striano, T., & Bertin, E. (2005). Coordinated affect with mothers and strangers: A longitudinal analysis of joint engagement between 5 and 9 months of age. *Cognition and Emotion, 19,* 781-790.

10. Bertin, E., & Striano, T. (accepted for publication) The influence of social context on infants' object processing. *European Journal of Developmental Psychology.*

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Introduction

Fundamental Functions of the Visual System

To function efficiently in the physical and social world, the visual system needs to perform many fundamental functions. For example, it needs to detect and individuate objects in complex scenes containing many objects, segregate them from their backgrounds, and perceive their boundaries and parts that define them as entities. To complicate these tasks further, there are people who interact with and communicate about objects. This puts additional demands on the perceptual system in that faces, voices, emotions, as well as peoples' intentions must be perceived, recognized, and understood. Much work has been done in investigating adults' performance in these fundamental object and social perception tasks. Researchers such as Biederman (1987), Marr & Nishihara (1978), or Treisman (1993) studied the mechanisms and processes underlying visual object perception. Others such as Tanaka and Farah (1993) or Simons & Levin (1997) examined the mature visual systems' perception of faces and social events. The question then arises as to how these abilities come into place. Might the visual system be innately endowed with some of its extravagant capacities? Do some perceptual abilities enjoy a short postnatal development, while others develop slowly and over a longer period of time? Might we even loose some perceptual competencies during early development? Research on infant and child development has shed much light on these and similarly relevant questions. Infant research in particular has contributed immensely to our understanding of the developmental origins of the human mind and the principles that guide its workings. The present work adds to the current infant literature in two important areas: (a) visual object and face perception and (b) social cognition.

Infancy as a Field of Study

Infancy as its own field of study lagged behind the emergence of modern psychology in the late nineteenth century. Prominent psychologists of those days, such as Wilhelm Wundt (1832-1920), did not consider children and infants as research subjects worthwhile studying. It took several decades for developmental psychology, and in particular infancy research, to become established, accepted, and recognized in mainstream experimental psychology. However, over the past 40 years psychological work on infancy has flourished and has changed our image of the infant from the physically and psychologically fragile creature with possibly no intellect to the competent, enlightened infant.

Infancy by definition is the period in which one is "unable to speak". This clearly marks it as a distinct time in human development and separates it from other species' ontogeny. Indeed, psychologists have long realized that extrapolating from human adults' or animals' performance on perceptual and social tasks to infants' behavior is not warranted both from a theoretical and methodological standpoint. At the same time it was recognized that most exciting and important changes take place during this time of human development (Piaget, 1952). Piaget was one of the first developmental psychologist who intensively studied the behavior of young human infants. His groundbreaking work inspired many generations of infant researchers. He had a tremendous impact on our understanding of child development and on the field of infancy studies.

Undeniably, the rapid developmental changes from a newly born, seemingly incompetent infant to a talking, walking, inquisitive, and independent toddler are staggering. This led to the realization that early abilities, their developmental course and continuity (or lack thereof) into later childhood deserve scientific inquiry and that establishing infant research as its own field of study was a worthwhile endeavor. The systematic study of the human infant's behavioral development is not only important in its own right but also for our understanding of how early abilities become translated into their mature forms. Indeed, understanding infants' experiences with the world may reveal the building blocks that make up the minds of adults.

Methods used in Infant Research

Once infancy was recognized as an important period of life worthwhile studying scientifically, new suitable methods needed to be devised. As mentioned earlier, infants are yet unable to express themselves with conventional symbols or referential systems. Thus, developmental psychologists had to invent special techniques to document the behavior of their nonverbal subjects. In their quest to decipher the infant's world, infancy researchers can either observe infants or experiment on them directly. Groundbreaking work in the latter was done by Robert Fantz (1958). He presented infants with two visual stimuli and observed their *spontaneous visual preference*. If one stimulus is preferably attended to it implies that the infant can discriminate between that stimulus and the one which it is paired to, and that the preferred stimulus holds some inherent importance to the observer, hence the baby's preference. Early research has shown that even very young infants have distinct visual preferences (Fantz, 1961; Johnson, Dziuarwiec, Ellis, & Morton, 1991).

Two other important principles in infant behavior are: (1) upon repeated presentation of a visual stimulus, infants' attention begins to wane and (2) after sufficient familiarization to an image, infants' attention and looking behavior is driven to novel stimulation. This *habituation* (1) and *novelty* (2) phenomena can be used by infant researchers to investigate discrimination and recognition abilities. Thus, one extension of the *habituation* paradigm is the *habituation-novelty* technique. The basic method is to first familiarize infants to an image until their visual attention declines and subsequently test them for their discrimination/recognition abilities by pairing the familiar image with a novel one. If infants devote the greater part of their visual fixation to the novel image, infants' discrimination/recognition of, and memory for, the familiar/old image is inferred. Numerous studies utilizing this approach have investigated infants' immediate and delayed discrimination/recognition abilities of various visual patterns and objects (e.g., Quinn & Bhatt, 1998; Yonas & Arterberry, 1994). Generally this research reveals that young infants can discriminate subtle differences between visual stimuli and that object, patterns, or events can persist in memory for several weeks (e.g., Frick, Colombo, & Allen, 2000; Rovee-Collier, 1993).

Several models of infants' immediate and long-term discrimination and retention suggest that during habituation a mental representation (or mental trace) of the familiar item is formed, which is accessed during the familiar-novel item comparison (Bahrick & Pickens, 1995; Courage & Howe, 1998; 2001; Hunter & Ames, 1988;). If the information of the initial stimulus was sufficiently encoded, the novel item can easily be distinguished/recognized from the familiar one and the infant will exhibit a novelty preference. Incomplete encoding of the initial stimulus results in a weak/incomplete mental representation that may lead to a preference for the familiar item during discrimination/retention testing or even a null preference. Thus, it has been concluded that the type of visual preference (novelty, familiarity, null) depends, among other things, on the completeness of information encoding during the habituation phase.

The habituation-novelty technique has been described in some detail because the first six research papers presented in this work utilized this method. However, other techniques are used in infant research. Infants' reactions to social stimuli are often measured by directly observing their facial expression, vocal output, behavior towards self and others, or manipulation of object presented within the social situation. For instance, infants' emotional and vocal expression during mother-child interactions can be noted and recorded. Furthermore, infants' reaction to, handling of, or cooperative play with objects offered by the social partner can be recorded and systematically interpreted. The infant's social behavior can be observed in naturalistic environments with little to no involvement on the part of the experimenter or in more controlled laboratory settings. Thus, observation of spontaneous social behavior and controlled experimental methods are often combined to create more contrived situations. The social cognition studies presented in this work employed such *direct experimental observation* methods.

Overview of Presented Research

In the following work, I will review 10 research papers. The first six studies investigated infants' visual processing of different kinds of relational information in objects and faces. The method used in these set of studies is the habituation-novelty paradigm as described above. In infants' perceptional research, a large part of experimental planning goes into the development of visual stimuli. This is to ensure that the aspects of the task truly test the ability under study. Of course, this is true for any kind of psychological investigation but becomes especially important and challenging when one deals with nonverbal participants as is the case for infant researcher. Therefore, the visual stimuli used in the first set of studies will be described in some detail and, whenever possible, augmented with examples.

The last four studies presented in this work examined infants' responses to a social partner's interactional style in face-to-face exchanges and their processing of objects within different social contexts. Established face-to-face procedures as well as joint engagement sessions between an infant, a social partner, and an object were used in the social cognition studies. They will be described in more detail later.

Spatial Relational Processing in Infancy: Information in Objects and Faces

Object Perception: Spatial Relational Processing among Object Parts

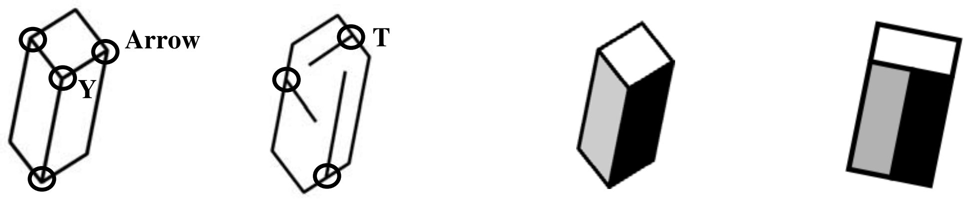
Objects are defined by many attributes (e.g., color, shape, size, orientation, spatial relation among object parts). The visual system's ability to accurately perceive single features and correctly *combine* object-defining attributes is absolutely necessary to correctly identify objects in visual scenes. For example, in a scene depicting a yellow banana beside a red apple, one needs to identify the single features in the scene as well as the specific way they belong together. Only this way can one arrive at a veridical percept and not, as in the example above, at a red banana beside a yellow apple. Similarly, the specific spatial relation of the two lines that distinguish a T from an L need to be correctly identified in order to make a valid differentiation. Many theories of visual perception assume that the visual system engages in a featural analysis of the visual scene (e.g., color or shape information) *prior* to the encoding of the relations among these features or object parts (e.g., what color *goes with* what shape) to generate holistic representations (Treisman, 1993; Treisman & Gelade, 1980). Consistent with this model, research with human adults that examined the differences between featural and relational processing (e.g., Julesz, 1984; Treisman, 1993; Treisman & Sato, 1990; Wolfe, 1998) indicates that featural discrepancies in the visual scene are detected much faster (e.g., finding a green T among red Ts; finding an O among Ts) than discrepancies based on relations among features (e.g., finding a green T among Green Xs and brown Ts; finding an L among Ts). It has been suggested that the discrepancy in speed of detection represent the functioning of the preattentive and attentive system, respectively (Treisman, 1993; Wolfe, 1998).

Prior research with infants has also indicated that discrepancies based on individual features are much easier to detect than discrepancies based on feature relations (e.g., Quinn & Bhatt, 1998; Younger & Cohen, 1986). This suggests that infants, like adults, process feature-based discrepancies more readily that relation-based ones. These results support the theory that qualitatively different visual mechanisms are involved in adults' and infants' processing of featural versus relational object attributes.

As implied above, there are various types of object-defining relational information. Conjunctional relations among object features refer to the specific *binding* of attributes that delineate an object (what *goes* with what). Important to the topic of the present work is the type of relational information that is concerned with the way in which different object parts or segments spatially relate to each other. In particular, spatial relations of lines, that in their arrangement depict line drawings implying either three-dimensional (3-D) or two-dimensional (2-D) structure will be discussed first (research paper 1 & 2). The spatial arrangement of shape segments that define an object's contour and form will be discussed in the subsequent papers (research paper 3 & 4).

Infants' Sensitivity to Pictorial Line Junction Cues (Research Paper 1)

Models of object perception assume that edges and line junctions are critical for the retrieval of information concerning object shape and spatial layout (Biederman, 1987; Enns, 1992). One prominent view put forth by Enns and Rensink (1991) assumes that three kinds of



(a) (b) (c) (d)

Figure 1: *Line junctions in polyhedral objects. Line drawing (a) and (c) readily signal 3-D structure, whereas (b) and (d) do not lend themselves to an easy 3-D interpretation.*

trilinear junctions are possible in 2-D renderings of scenes containing polyhedral objects: T junctions, Y junctions, and arrow junctions (see Fig.1). A combination of Y and arrow junctions convey 3-D structure and orientation of depicted objects. T-junctions typically correspond surface markings and to boundary edges formed by surface occlusion (found at intersections of overlapping surfaces) and hence only indicate the relative depth of two objects. Thus, line junction information convey depth and spatial layout to the observer when 3-D scenes are presented in photographs and pictures, and are hence called pictorial depth cues.

A number of behavioral studies revealed that adult humans readily utilize line junctions contained in static images to derive 3-D shape and orientation information. Moreover, adults rapidly detect orientation discrepancies in visual scenes depicting 3-D objects like the ones depicted in Fig. 1 (*a* & *c*), but not of similar scenes in which objects do not have a 3-D interpretation (see Fig. 1; *b* & *d*). Thus, it has been suggested that the former orientation discrepancies are detected immediately (i.e., they *pop-out*) because they are processed effortlessly and independent of the number of other objects in the scene (i.e., parallel processing), while the search for the latter origination change is effortful and increases with the number of objects in the scene (serial processing) (Attwood, Harris, & Sullivan, 2001; Enns & Rensink, 1991, see also Enns, 1992; Sun & Perona, 1996). It is believed that the two types of searchers reflect the functioning of the preattentive and attentive visual systems, respectively (e.g., Treisman, 1993; Wolfe, 1998).

The experiments described in research paper 1 (and 2) were inspired by the above findings with adults and the subsequent theories and perceptual models derived from these results. In particular, we asked whether infants, like adults, are sensitive to changes in orientation of line drawings that appear to have a 3-D structure but not to comparable changes in line drawings that do not have a 3-D structure interpretation. That is, infants processing of the spatial relations between lines that determine 3-D structure for adults (line drawing *a* in

Fig. 1) was compared to their processing of line junction relations that do not have a 3-D interpretation (line drawing *b* in Fig.1). To test this, we employed a paradigm that examines infants' attentional engagement akin to the *pop-out* phenomena in adults (Quinn & Bhatt, 1998). It is essentially a habituation-novelty paradigm in which 3-month-old infants were habituated to two homogenous arrays of line-drawings that appeared to be either three-dimensional cubes (see Fig. 1; *a*) or comparable flat 2-D images (see Fig. 1; *b*) oriented in a specific direction. Immediately after familiarization, infants were confronted with two test patterns, one containing an individual element tilted at a novel orientation amidst familiarly oriented elements and another pattern containing a single element in familiar orientation embedded in elements of novel orientation. The logic of this method assumes that if the individual newly oriented element *pops-out,* it should attract and hold infants' attention manifested in their visual preference for this test pattern over the one that displays a single familiarly oriented element.

The results revealed that 3-month-olds preferred to look at the test pattern with the single newly oriented element in the 3-D condition but at the test pattern with the single familiarly oriented element in the 2-D condition (see Fig, 2, research paper 1). Thus, akin to *pop-out* in adults, rotation discrepancies defined by a novel orientation in images that depicted 3-D objects attracted and held infants' attention, whereas comparable discrepancies in 2-D images did not. It seems then that infants, like adults, are sensitive to spatial relations in line junctions that convey ecologically relevant information about object shape and orientation.

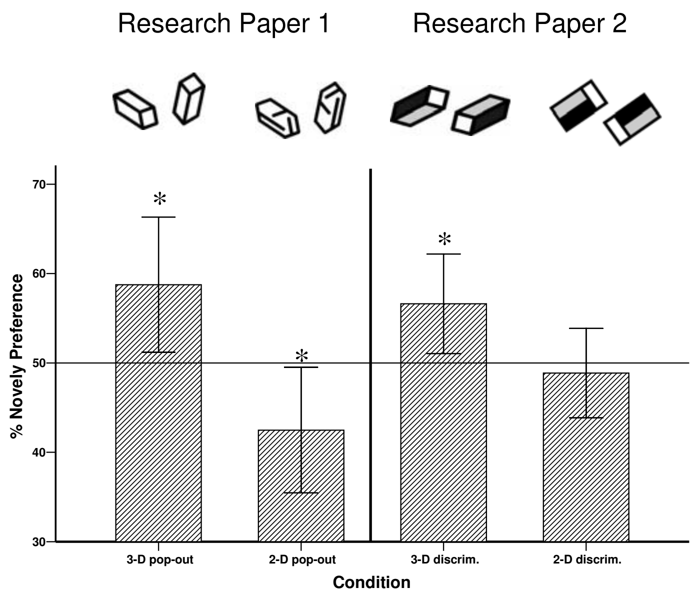


Figure 2: *Results of research papers 1 and 2. Asterisks indicate significant above/below 50% chance-level performance.*

The sensitivity to pictorial 3-D line junction cues implies that at least rudimentary aspects of the derivation of 3-D structural information from static images is available by 3 months of life. Prior research suggests that, on the one hand, derivation of complete 3-D form from pictorial cues does not develop until later in life, between 5 and 7 months of age (e.g., Kavšek, 1999; Yonas & Arterberry, 1994) and that, on the other hand, under certain experimental conditions, infants younger than 5 months of age are capable of responding to pictorial 3-D cues (e.g., Bhatt & Waters, 1998; Kavšek, 2003). A visual system that is sensitized to process pictorial cues pertaining to three-dimensionality seems ecologically advantageous given that retinal input is invariably two-dimensional.

As suggested earlier, research has found that only discrepancies based on fundamental features of objects and not relation-based object differences are easily detected and discriminated by human adults and infants (e.g., Treisman, 1993; Younger & Cohen, 1986). The present findings challenge this assumption because orientation differences in line drawings containing 3-D cues, but not comparable line drawings lacking 3-D cues, were discriminated by infants and engaged their attention. Our results are analogous to findings with adults who readily discriminated orientation changes of objects that appear to be 3-D prisms but not of patterns that matched the 3-D prisms in terms of complexity but lacked a 3-D interpretation (Enns & Rensink, 1991). It needs to be noted that the difference between the two types of line drawings is brought about by rearranging the spatial relations between the lines of the triliniar junctions. Thus, the set of fundamental features that engage the human visual attentional system might be different from the set of simple features originally thought to be the building blocks of object perception. Indeed, the set might include *relations* of more primitive fundamental features of objects, especially when they convey ecologically important information as is the case in 3-D line junction cues.

Infants' Sensitivity to Pictorial Orientation Cues in the 3-D Depth Plane (Research Paper 2)

In the above study, we established infants' selective sensitivity to spatial relations between lines that for adults determine 3-D structure and orientation. However, the orientation changes of the line drawings in the previous study involved changes in all three axes of the Cartesian coordinate system. That is, in addition to an apparent 3-D depth change (*z* axis—the depth plane), the discrepant line drawing also differed from the surrounding line drawings in its 2-D orientation (*x* and *y* axes—the picture plane). Thus, infants in the 3-D *pop-out* condition of the study described in research paper 1 could have based their discrimination on the *combination* of changes in all three axes. Therefore, it is not clear whether infants are sensitive to 3-D cues in static images that signal orientation changes only in the 3-D depth plane. We examined this issue by presenting 3-month-old infants with displays containing elements such as depicted in Fig. 1 (*c* and *d*). In contrast to the stimuli used in research paper 1, the individual discrepant element was unaltered in its picture-plane orientation and only the drawing's central lines changed, which determined its new orientation in the 3-D depth plane. Besides examining infants' sensitivity to pictorial orientation cues, this stimulus manipulation constituted further examination of infants' sensitivity and processing of spatial relational information among object parts.

The results show that 3-month-old infants discriminated a change that appeared to be a 180-degree rotation of a 3-D cube in the depth plane but failed to discriminate a comparable change in flat 2-D images (see Fig. 2; research paper 2). Combined with our previous study (research paper 1), these results suggest that infants as young as 3 months of age are selectively attentive to line junction cues that the adult's visual system uses to perceive 3-D layout and structure. This is true whether the orientation change of the two-dimensional renderings of the polyhedral objects is in the picture plane or in the 3-D depth plane.

We also presented the stimuli depicted in Fig. 1 (*c* and *d*) without shading to examine whether the lack of an additional pictorial cue (i.e., surface shading) had a deteriorating effect on infants' ability to discriminate orientation changes in the 3-D depth plane. The results revealed that infants were no longer able to discriminate the 3-D rotation changes. This is not surprising given that shading information also influences the speed and ease at which adult observers perceive scenes containing polyhedral objects (e.g., Attwood et al., 2001; Sun & Perona, 1998). However, the results with the shaded stimuli were not simply due to the detection of changes in luminance patterns provided by the 180° rotation of the target item. Both the 3-D and the 2-D stimuli provided shading information of the same kind, but only when the images depicted apparent 3-D objects were infants able to discriminate orientation changes.

Across several studies, we demonstrated that 3-month-old infants were sensitive to orientation changes of line drawings but only when the images possessed a 3-D structural interpretation. Infants' selective attention to 3-D line junction cues is consistent with a number of models that assume that edges and junctions are critical for object recognition (e.g., Biederman, 1987). Moreover, infants' attention to discrepancies in 3-D line junction cues was engaged in a similar manner as discrepancies in simple fundamental features such as color, shape, or line orientation. Thus, spatial relational information in 3-D line junction cues might be an emergent feature that *pops-out* (and thus is processed parallel and preattentively) for adults and attract and engage infants' visual attention comparably. Because of this property, 3-D line junction cues may be part of the set of fundamental features.

Infants' Perception of Concave and Convex Object Boundaries (Research Paper 3)

The processing of the specific spatial arrangement of object parts is crucial for a veridical interpretation of the visual percept. For example, when a half-circle is attached to the right side of a square, we are likely to perceive a cup; when it is attached to the top of the square it appears to be something entirely different—a suitcase. Similarly, when the individual lines that constitute a hexagon are spatially rearranged, a different shape emerges. A hexagon is inherently a convex shape (see Fig. 3; *b*). When the spatial location of sections of the hexagon's contour are altered, a concave element emerges (see Fig. 3; *a*).

(a) (b)

Figure 3: *Elements with concave (a) and convex (b) contours.*

It has been suggested that points of curvature-changes along the edges of objects are significant for part decomposition, which in turn is important for object perception and subsequent representation (e.g., Biederman, 1987; Marr & Nishihara, 1978). The perception of concavities seems especially important in the computation of basic volumetric object parts. Indeed, at the point where a part connects with the rest of an object (e.g., where the handle connects to the cup), there is usually a concave discontinuity in the contour. There is considerable empirical support for adults' superior processing of concave-defined contour discontinuity (e.g., Hulleman, te Winkle, & Boselie, 2000). Thus, adults derive object parts by attending selectively to concavities in shape contours.

Developmental psychologiests also addressed many aspect of how infants attend to information in edges of objects. For example, research revealed that 7-month-old infants are more likely to notice changes in edges of objects than in objects' surface markings (Yonas & Arterberry, 1994). Moreover, as described in the preceding paragraphs, my colleague and I demonstrated that 3-month-olds attend to line junctions in edges that signal 3-D structure and orientation information to adults (research paper 1 and 2). Against this background, we examined infants' sensitivity to concavities and convexities in edges by using the habituation-novelty preference paradigm and stimuli such as depicted in Figure 3. In particular, infants' discrimination of concave targets among convex distractors and vice versa was examined.

The results revealed that infants as young as 5 months of age treat concavities as special regions of an object's contour. In fact, infants exhibited an asymmetry in the detection of concavities and convexities in that they were able to detect discrepant concave elements embedded among convex distractors but failed to detect convex elements among concave distractors. Adults also demonstrate such asymmetries in search tasks for concave and convex targets (e.g., Hulleman et al., 2000). Such asymmetrical results have been used as an index of the preattentive processing of fundamental features. That is, if an element with a particular feature is detected rapidly among distractors that do not contain that feature but the reverse is not true, then it is assumed that the feature is processed preattentively (e.g., Treisman, 1993).

It was argued before that 3-D line junction cues might be an emergent feature deserving inclusion in the set of fundamental features because they attract and hold infants' attention akin to the *pop-out* effect found in adults. Likewise, it might be argued that concavities also constitute fundamental features because they yield effective, fast searches in adults (i.e., parallel processing) and hold a greater salience for infants than convexities (research paper 3). However, we did not examine whether infants' detection of concave elements among convex distractors was a result of *pop-out* or parallel processing. Thus, we only make tentative claims that concavities might be fundamental features in infancy. Nevertheless, we demonstrated that stimulus attributes that *pop-out* for adults (i.e., concavities) also capture infants' attention. Thus, regions of concavities in objects' contours are significant to adults and for infants as young as 5 months of age. Indeed, infants' sensitivity to concave curvatures might be the first step in object part decomposition as suggested by models such as Biederman's (1987) recognition-by-components model.

Infants' Discrimination Abilities in *Good* and *Poor* Form Patterns (Research Paper 4)

The previous study revealed that concavities are contour areas that attract and guided infants' visual attention. This ability relies on the spatial relational processing of the shape's segments that define its contour. Spatially rearranging segments of an object's or shape's boundary can render the same in a *good* or *poor* form. The goodness of a form can be defined by many attributes such as symmetry, number of axes of symmetry, or closure of form. In the

(a) (b)

Figure 4: *Good from pattern (a) and poor from pattern (b).*

patterns depicted in Figure 4, a *good* form (a) is transformed into a *poor* form (b) solely by spatially rearranging some of the pattern's segments. In particular, the *poor* form pattern has been created by turning two of the square's four corners inward. By doing so, grouping of the pattern's elements, which can take place on the basis of continuation between line endings, closure, or shape symmetry, has been made difficult. Thus, introducing variability in the array's elements made the *poor* form's elements heterogeneous, while the *good* form's elements are homogeneous and thus easily grouped. Research with adults has shown that such manipulations made target detection in the former more effortful than in the latter (Donnelly, Humphreys, & Riddoch, 1991). Subsequently, Duncan and Humphreys (1989) devised a model which postulated that a target will acquire attentional strength to the extent that it is dissimilar from the nontarget elements in the array and to the extent that the nontarget elements can be perceptually grouped together.

Prior research with infants indicates that they, like adults, are sensitive to the arrangement of pattern elements. For instance, Humphrey and his colleagues (Humphrey, Humphrey, Muir, & Dodwell, 1986) found that 4-month-olds habituated more quickly to *good* and *medium* form patterns than to *poor* form patterns (with goodness of a pattern defined by the number of axes of symmetry possessed by the pattern). Moreover, Van Giffen and Haith (1984) demonstrated that by 3 months of age, infants are sensitive to a pattern's visual organization when defined by the Gestalt principle of good continuation.

The question then arises as to how changes in a form's goodness affect infants' target detection. We tested this by first habituating 5.5-month-old infants to *good* or *poor* form patterns such as depicted in Figure 4 and subsequently tested them for discrepancy detection by presenting the same patterns, but now with the right-hand corner turned inward, respectively. Thus, we examined infants' ability to discriminate a misoriented element in a *good* form (where surrounding elements are easily grouped) versus in a *poor* form (where surrounding elements are not easily grouped because of their heterogeneity). We hypothesized that spatially rearranging the same pattern's elements affects discrepancy detection.

The data indicated that infants discriminated a misoriented element when the discrepancy modified a *good* form (as evidenced by their novelty preference for the test pattern) but not when it modified a *poor* form. Thus, interfering with the grouping by modifying the spatial arrangement of the pattern's elements deleteriously affected infants' discrimination ability. Put another way, the results from research paper 4 revealed that heterogeneity, induced by variability in the spatial arrangement of an array's elements, interferes with 5.5-month-olds' discrimination of a misoriented element in the array. These results are consistent with prior reports indicating that infants are sensitive to the spatial arrangement of pattern elements (e.g., Humphrey et al., 1986).

Segregating objects from its surrounding is a fundamental function of the visual system. We demonstrated that for infants, as is the case for adults, discriminating an object from background elements that are readily grouped is easier than when the background elements are heterogeneous and therefore not promptly grouped together. Alternatively, it could be argued that infants simply discriminated a perfectly symmetrical form (see Fig. 4; *good* form) from a non-symmetrical form (test pattern when right-hand corner was turned inward) and that this was easier than discriminating two non-symmetrical forms. Indeed, symmetry may well be a principle that infants this age use to generally discriminate between stimuli. However, we were interested in infants' ability to detect the novel spatial relational arrangement of a *good* and *poor* pattern's elements. We found that 5.5-month-olds were able to do so in the former but not the latter pattern type. Thus, infants this age are sensitive to the spatial relational arrangement of object parts that constitute either a *good* or a *poor* form.

Summary Spatial Relational Processing among Object Parts (Research Paper 1-4)

Across several studies, we investigated young infants sensitivity to spatial relations among object parts. We examined this issue by (a) manipulating the lines of trilinear junctions to either render an appearance of 3-D objects or of flat 2-D patterns (research paper 1 & 2), (b) changing the spatial location of sections of a hexagon's contour to create concave and convex elements (research paper 3), and by (c) spatially rearranging elements of a *good* form pattern to transform it into a *poor* form pattern (research paper 4). These object properties—3-D pictorial cues, convexity, and aspects of *good* form patterns—are used by the adult's visual system to derive important ecological information such as object structure and form, spatial layout, or figure-ground boundaries. Our data suggests that infants, like adults, are sensitive and selectively attentive to ecologically relevant complex properties of objects. These results let us to conclude that not only elementary features such as color or shape, but also ecologically relevant complex properties of objects that have to be computed by combining many simple features (such as 3-D pictorial cues or convexity) might also be rapidly available to the preattentive system.

Up until now, I have only discussed infants' spatial relational processing of object parts. However, spatial relational information is also found in other stimulus classes. The next sections are devoted to infants' sensitivity to spatial relational information found in the human face.

Face Perception: Processing of Different Spatial Relational Information in Faces

The human face is one of the most complex stimulus encountered by the young infant. Aside from being three-dimensional, it has areas of high and low contrast, moves in respect to itself and to the infant, and emits sounds. In addition to that, it affords invariant relationships of features (position of eyes, mouth, and nose) as well as changing ones (changing physiognomy with expression of emotions). On a social level, the face displays emotions, interacts with the infant, and responds to the infant's behavior. Despite this stimulus complexity, infants possess a remarkable ability to discriminate and remember faces and to discern meaning and intention from it. In order to understand the origin and developmental course of infants' face perception (both on a perceptional and social level), it is necessary to examine infants' responses to the above mentioned aspects of stimulation. Ever since Fantz's (1958, 1961) original studies, there has been considerable interest in infants' face perception.

The focus of investigation in research paper 5 and 6, is on young infants' processing of different kinds of spatial relational information in the human face. It has been suggested that, aside from featural information processing (eyes, mouth, and nose), two kinds of relational information—first-order and second-order relational information—are involved in adults' processing of faces (e.g., Diamond & Carey, 1986). First-order relations refer to the gross, qualitative spatial relations among facial features (e.g., the nose is located above the mouth). Second-order relations refer to the fine spatial relations among features (e.g., the metric distance between the nose and the mouth) in reference to a prototypical face. Diamond and Carey propose that to differentiate faces at a fully functional level, it is especially important to process variations in individual features and second-order relational information because all faces share the same first-order configuration.

There is considerable empirical evidence suggesting that infants are sensitive to first-order relational information within the first few months of life (e.g., Johnson & Morton, 1991; Valenza, Simion, Cassia, & Umilta, 1996). However, it is less clear whether infants and even children use second-order information. Some researchers suggest that adult-like sensitivity to second-order relational information might not be reached until middle childhood (e.g., Carey & Diamond, 1994). Others provide some evidence that at least by 7 months of age, infants are able to discriminate faces on the basis of second-order spatial relational information (e.g., Thompson, Madrid, Westbrook, & Johnston, 2001). The disagreement in findings and the general scarcity of empirical work investigating the developmental course of second-order relational processing were the impetus of the studies described in research paper 5 and 6. The importance of the study of second-order relational processing in early infancy also arises from the assumption that adults' expertise at processing faces derives from their ability to encode and utilize this kind of relational information (Carey & Diamond, 1994; Diamond & Carey, 1986). Thus, a better understanding of how adults become experts at processing faces requires an examination of the ability to process second-order relational information early in life.

The Thatcher Illusion and Face Processing in Infancy (Research Paper 5)

The current study investigated infants' second-order spatial relational processing via the Thatcher illusion. This illusion is experienced by adults who are exposed to a face in which the eyes and the mouth are inverted on an otherwise upright face (i.e., a "thatcherised" face). This stimulus manipulation bestows a grotesque expression on the face that is readily noticed by adults when the image is viewed upright. If, however, the entire "thatcherised" image is rotated 180º, the bizarre expression gives way to a more neutral appearance. The illusion of normal appearance causes adults' failure to quickly discriminate the "thatcherised" face from an unaltered face (e.g., Lewis & Johnston, 1997; Thompson, 1980).

It had been suggested that "thatcherising" a facial pattern changes second-order relational information *without* altering featural and first-order relational information and that, at least with adults, the illusion is caused by interfering effects of face inversion on the processing of second-order relational information (e.g., Freire, Lee, & Symons, 2000). In research paper 5, we investigated whether 6-month-old infants experience the Thatcher illusion. We hypothesized that if infants, like adults, detect "thatcherisation" changes in upright but not in inverted presented faces, it would be evidence consistent with the notion that infants are also sensitive to second-order relational information.

To examine this we employed the habituation-novelty preference paradigm and presented 6-month-old infants with the stimuli depicted in Figure 5. In particular, infants' ability to discriminate between an unaltered face and a face in which the eyes and the mouth were turned upside down was tested in an upright and inverted condition. As dictated by the

Figure 5: Unaltered faces (a and c) and faces where the eyes and the mouth were turned upside down (b and d) in the upright and inverted position.

logic of the paradigm, a visual preference for the novel stimulus (i.e., the one different from the habituation stimulus) was taken to be indicative of successful discrimination.

The results supported our hypothesis. That is, 6-month-old infants discriminated the changes between an unaltered and a "thatcherised" face when the faces were presented upright, but failed to discriminate the same changes when the faces were presented upside down. Thus, 6-month-olds exhibited a phenomenon analogous to the Thatcher illusion in adults in that their discrimination of "thatcherised" faces was disrupted by inversion. Based on these results it is safe to say that by this age, infants are sensitive to second-order relational information afforded by faces—at least when assessed by the Thatcher illusion. Thus, our results were consistent with findings of previous face-processing research with infants (e.g., Thompson et al., 2001). However, the findings of research paper 5 left us with more questions than answers. We were particularly interested in the contrast between infants' sensitivity to first-order and second-order spatial relational information as well as the developmental course of the sensitivity to these different kinds of relational information.

Developmental Changes in Infants' First-Order and Second-Order Relational Information Processing (Research Paper 6)

In a series of studies, we further examined infants' sensitivity to first- and second-order relational information afforded by the face. First, we investigated whether 3-month-old infants exhibit the Thatcher illusion effect similar to the one exhibited by the 6-month-olds in research paper 5. Employing the same procedure and stimuli, we found that 3-month-old infants did not discriminate "thatcherisation" changes in either upright or inverted face images. Thus, 3-month-olds failed to evidence sensitivity to second-order information as measured by the Thatcher Illusion. This contrasts the findings of research paper 5 and suggest a developmental change in sensitivity to second-order relations. In subsequent experiments we further examined this developmental course as well as the one related to first-order relational information.

Although there is evidence linking the Thatcher illusion to second-order processing in adulthood and infancy (e.g., Bertin & Bhatt, 2004; Freire et al., 2000), this link is not direct. Thus, we thought to examine infants' ability to process second-order information more directly by assessing their ability to detect changes in the spacing between the eyes and between the nose and mouth in facial images. This stimulus manipulation adheres closer to the definition of second-order spatial relational information in the human face. Using the same general procedure as in research paper 5, 3- and 5-month-old infants were presented with the face stimuli depicted in Figure 6. In particular, we tested their sensitivity to changes in fine spatial relations among features by showing them unaltered face patterns (*normal*) and a distorted face patterns (*a* and *d*) in their upright position.

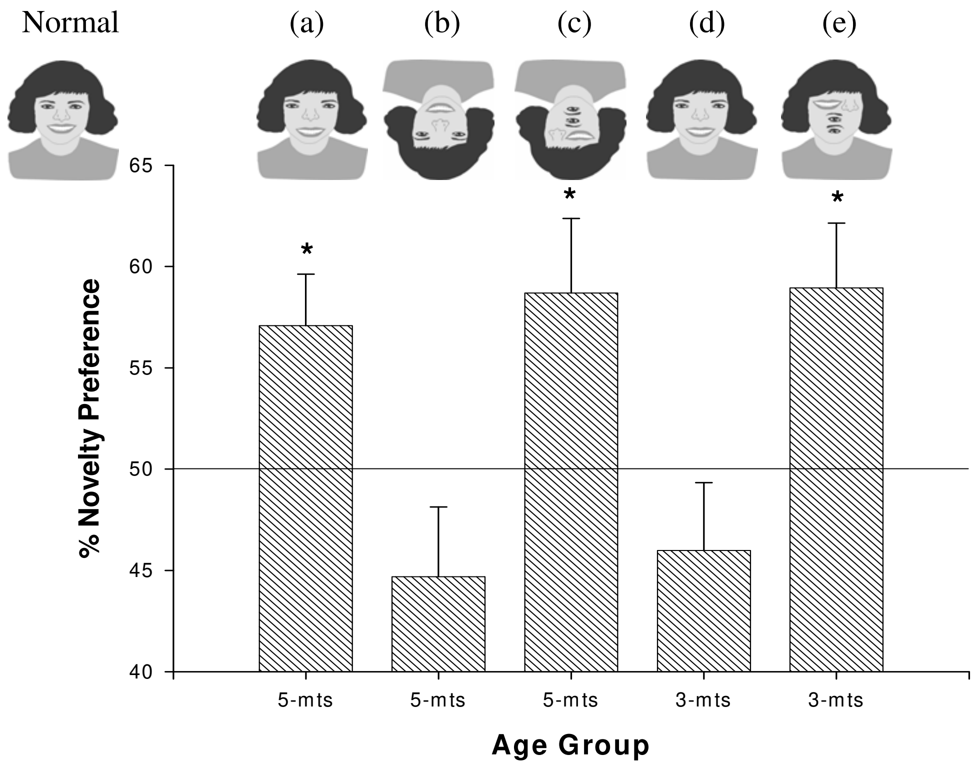


Figure 6: *Results and stimuli of research paper 6. Asterisks indicate significant above 50% chance-level performance.*

Figure 6 indicates that while 5-month-olds discriminated changes in the spatial relations among facial features (evidenced by the above-chance novelty preference), 3-month-olds failed to exhibit a sensitivity to the same changes. The results clearly suggest an age-related difference in the sensitivity to second-order relational information. The fact that 3-month-olds failed to show sensitivity to second-order relational changes induced by "thatcherisation" changes (research paper 5) as well as by changes in the metric distance between the eyes and between the nose and the mouth (research paper 6) bespeaks of a true lack of sensitivity to this kind of relational information. On the other hand, 5- to 6-month-olds' processing seems to be robust whether tested by the Thatcher illusion or more direct distortions of the fine spatial relations among features.

Given that 3-month-old infants failed to discriminate second-order relational changes, the question arises as to whether they are sensitive to other kinds of relational information, specifically first-order relations. Thus, in a subsequent experiment, 3-month-old infants were tested for their ability to discriminate first-order relational changes using the normal face pattern and a pattern in which the facial features were misoriented (see Fig. 6; *e*). The results revealed that infants had no difficulties discriminating first-order relational changes as indicated by Figure 6. This result was expected given a great number of empirical findings suggesting that infants this age and younger are sensitive to this kind of relational information (e.g., Johnson & Morton, 1991; Valenza et al., 1996). Thus, while 3-month-olds failed to discriminate second-order information, they discriminated first-order information in the same face pattern. This suggests a difference in the developmental trajectories of the sensitivity to first-order versus second-order relational information in faces.

Lastly, we were interested in whether inversion affects infants' face perception. Adults' processing of faces is typically less accurate and efficient when faces are presented inverted as compared to upright (e.g., Diamond & Carey, 1986; Freire et al., 2000). In particular, we investigated whether inversion affects the processing of the different kinds of spatial relational information differentially. To this end, we tested 5-month-old infants with inverted face patterns containing either first- or second-order relational changes (see Fig. 6; *c* and *b,* respectively). As suggested by the results presented in Figure 6, face inversion affected first- and second-order information processing to different degrees. Indeed, whereas the discrimination of first-order relational changes was not affected by inversion, infants no longer discriminated comparable changes in second-order relational information. In this respect, 5-month-olds' performance is similar to that of adults, for which face inversion appears to affect relational processing more than featural processing (e.g., Bartlett, & Searcy, 1993). Moreover, these results strengthen our previous findings in that inversion also disrupted second-order relational processing in the "thatcherised" face patterns employed in research paper 5.

Across several experiments we were able to demonstrate that 5-month-old, but not 3-month-old, infants are sensitive to second-order relational information afforded by the human face. This suggests that sensitivity to this kind of spatial relational information develops sometime between 3 and 5 months of age. Developmental changes in other types of relational information processing have also been found between the age of 3 and 5 months (e.g., Younger & Cohen, 1986). At the same time, first-order relational information processing is available after approximately 3 months of postnatal development. Thus, it seems that the sensitivity to the two kinds of spatial relational information in the human face—first-order and second-order—have different developmental trajectories.

Summary Processing of Different Spatial Relational Information in Faces (Research Paper 5-6)

In two research papers, we investigated infants' sensitivity to first- and second-order relational information afforded by the human face. The observed dissociation in the developmental trajectories of sensitivity to first-order versus second-order relations and the fact that for infants, as for adults, inversion disrupts second-order but not first-order information processing are consistent with the qualitative distinction that several researchers have made between these two kinds of relational information processing in adulthood (Carey & Diamond, 1994; Diamond & Carey, 1986). Thus, it is possible that the mechanisms of face processing in infancy are similar to the ones in adulthood. However, they are likely not exactly the same given that even children as old as 14 years of age may not process faces in the same manner as adults. The findings of research paper 5 and 6 do not resolve the debate about whether or not there are qualitative changes in face processing from infancy to childhood to adulthood. However, our results do indicate that the ability to process second-order information is available relatively early in life. Therefore, any developmental changes that are found later in life are not based on an *inability* to process this kind of information.

General Discussion of Spatial Relational Processing in Infancy

Across several studies, employing different stimuli, we demonstrated that infants possess remarkable abilities in processing spatial relational information in objects and faces. In many regards, infants' sensitivity to spatial relational information follows adult patterns. This, of course, should not simply be taken as evidence for the absence of perceptual development from infancy to adulthood. For example, infants' sensitivity to pictorial depth cues as investigated in research paper 1 and 2 may not necessarily translate into infants' ability to extract *complete* 3-D form or spatial meaning. However, it nevertheless demonstrates an early sensitivity to line junction cues that the mature visual system uses to perceive 3-D layout and structure. This early sensitivity might be a predecessor to infants' later functional responses to pictorial depth cues (e.g., deriving complete 3-D form and spatial meaning; reaching to the apparently nearer object). Similarly, while from a very early age on, infants possess remarkable abilities in discriminating and remembering faces, it seem to take several months of postnatal experience with faces to process this class of stimuli at a higher level—one involving second-order relational information processing. This assumption is consistent with neuronal models of the development of face processing (e.g., Morton & Johnson, 1991). Thus, although many aspects of object and face perception are operational and functional shortly after birth, there may also be significant developmental changes within infancy and between infancy and adulthood.

The results from research paper 1-6 suggest that infants' visual system is sensitive to some of the same building blocks that operate in adults' object and face perception. However, this must not necessary imply that the same *mechanisms* underlay the early and mature visual system's perception of objects and faces. Similarly, sensitivity to the same perceptual building blocks might nevertheless lead to different perceptual *experiences* and mental representation in infants and adults. Moreover, while early sensitivity to different kinds of spatial relational information was established in research paper 1-6, the level of *usage* of this kind of information might change between infancy, childhood, and adulthood.

Face processing, as investigated in research paper 5 and 6, is also critical for the effective functioning in social settings. Thus, it is important to investigate infants' ability to process faces in order to better understand their performance and development in the social context. I will turn to this research area in the next sections.

Social Cognition: Infants' Responses in Dyadic and Triadic Interactions

Dyadic Interactions

Infants do not only show remarkable abilities in the processing of faces perceptually, but also a fundamental need for socially engaging with this special class of stimuli. Shortly after birth, infants prefer face-like compared to non-face-like patterns and human over non-human sounds (e.g., Friedlander, 1970; Johnson et al., 1991) suggesting a readiness for interpersonal contact. Parents and caregivers also encourage infants from birth on to socially interact with them. Indeed, warm face-to-face interactions, with exaggerated facial and vocal expressions displayed by the adult social partner, are joyful for the infant and important for his/her healthy development. Aside from being pleasurable experiences, such intimate, one-to-one interactions are the cradle of social understanding—not just of others but also of oneself.

Some 30 years ago, researchers began to investigate infants' responses to dyadic interactions using the still-face paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978). In this paradigm, a normal face-to-face interaction between an infant and an adult is interspersed with a period in which the adult suddenly freezes, becomes unresponsive, and poses a stationary neutral face while maintaining eye-contact (i.e., still-face period). Infants as young as 2 months of age react to the adults' unresponsiveness during the still-face period with decreased visual attention and positive affect (Tronick et al., 1978). Such results are interpreted in terms of infants' attentive and affective attunement to social partners and their rudimentary expectations about the nature of face-to-face interactions. Moreover, it reflects the infant's emotional experience during a perturbation of normal social interaction (i.e., during the still-face period) and his/her ability to reorganize behavior following an emotionally distressing situation (i.e., during the subsequent normal interaction period). At a very basic level, the still-face effect is defined by a marked decline in visual attention and affective display from the normal dyadic to the still-face interaction. Infants usually exhibit a robust still-face effect by 3 months of age.

The Still-Face Response in the First 3 Months of Life (Research Paper 7)

Adamson and Frick (2003) reported that the bulk of empirical data on infants' responses to the still-face procedure is on infants between the ages of 2 and 9 months. The motivation behind the study described in research paper 7 was to provide data on infants' still-face response in the first 3 months of life. Thus, we examined the ontogenetic origin of infants' attunement in face-to-face interactions and consequently build an important bridge to what is known about the still-face response in older children.

There are several reasons why infants younger than 2 months of age may exhibit the signature still-face responses—decreased visual attention and smiling—in the face of an unresponsive social partner. First, as mentioned earlier, very young infants possess remarkable perceptual abilities and are capable of distinguishing even subtle differences between stimuli. Thus, it is possible that even newborns perceive the many perceptual differences between an engaging and an unresponsive social partner (e.g., facial movement, emission of sound). Second, given the social nature of human beings, the still-face response may be formed quickly in the first few weeks of life or not rest upon postnatal development and social experiences at all. Thus, by testing newborns and infants under 2 months of age, we were able to examine whether the still-face response may perhaps be innately determined (such as their affinity to look at human face patterns) or rest upon development and social experiences after birth.

In the study of research paper 7, we tested newborns, 1.5-month-olds as well as 3-month-old infants with the still-face manipulation. The results revealed that both older age groups exhibited a typical quadratic still-face response both in their visual and their affective behavior. The same was not true for newborns (see Fig. 7). Although newborns decreased their visual attention from the initial normal face-to-face interaction to the still-face period, they did not resume their initial level of visual attention during the reunion phase of the second normal interaction.

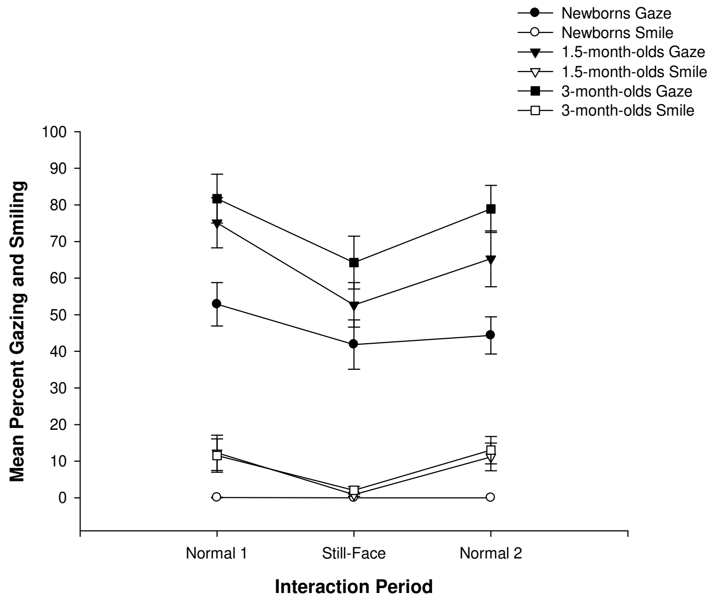


Figure 7: *Infants' performance in the normal and still-face interaction periods.*

In general, we did not find the signature behaviors of the still-face manipulation in newborns. This countermands the assumption that the still-face phenomena, so typically found in older children, is an unlearned, perhaps innate, social response. It seems more likely that postnatal social experience is important for infants to learn what constitutes a violation of natural dyadic interactions.

The lack of observed variation in infants' behavior is notoriously difficult to interpret. It is still possible that the newborns in this study were sensitive to the still-face manipulation but simply lacked the expressive repertoire to reveal their knowledge. Furthermore, it is conceivable that the break in social contingency was not perceived as overly disturbing by the newborn (as long as there was a face to look at) and thus did not trigger a behavioral change. However, a few weeks later, by 1.5 months of age, infants seem attentively and affectively attuned to their social partners. This suggests that by this time, infants have rudimentary expectations about the nature of interpersonal dyadic interactions. Thus, if postnatal social experiences are indeed necessary to form expectations about face-to-face exchanges, they are attained quickly and seem to be in place by about 1.5 months postnatal.

Contribution of Facial and Vocal Cues in the Still-Face Response (Research Paper 8)

In a natural caregiver-child face-to-face interaction, the infant perceives the social partner's engaging overtures through several senses—vision, hearing, and perhaps even touch. When the infant changes its behavior during the abrupt and dramatic loss of social contingency and reciprocity, it is often not clear which sensory information produces this effect—all in tandem or one predominantly. The contribution of different sensory information to the still-face effect was investigated in research paper 8.

When caregivers initiate communicative contact with their infants, they naturally present their face conspicuously to the infant, which makes them most *readable* and engaging. The face provides key information about the nature of others' behavior and feelings. Thus, the face seems to play a special role in early one-to-one interactions. Typically, interactions between adults and infants also involve vocal expressions—especially child-appropriate vocalization provided by the adult for the infant. In fact, it is often vocal communication alone that brings two people into social contact when, for example, the two are not in each others' direct line of sight. Thus, the voice must play an important role too.

In the still-face paradigm, as is the case in every-day adult-child interaction, normal interactions are typically characterized by the social partner being both visually and acoustically available to the infant. Moreover, the social partner's face (visual sensory input) and voice (auditory sensory input) are interactive and contingent upon the infant's behavior. The interactive nature and contingency of both communicative overtures (i.e., visual and auditory input) is lost during the still-face period, leading to the typical still-face response. This raises the question as to whether facial *or* vocal cues (or both in tandem) are responsible for the still-face response. There is some empirical evidence suggesting that only the loss of contingent facial cues leads to a still-face effect (e.g., Gusella, Muir, & Tronick, 1988).

However, there was a conflict between the visual and vocal information presented to the infants in the study by Gusella and his colleagues.

In the study of research paper 8, we assessed whether infants manifested a still-face response when visual and vocal cues were not in conflict. This was established by assigning 4-month-old infants to one of three conditions—(1) mothers engaged with their infants in natural face-to-face interactions (visual and vocal cues), (2) mothers mimicked natural interaction without emitting any audible speech sound (visual cues only), and (3) mothers spoke to their infants while out of infants' sight (vocal cues only). During the still-face period, infants lost visual *and* vocal cues, only visual, or only vocal cues, respectively.

The findings indicated that as long as there was a still-face, regardless of whether or not it was previously accompanied by an audible interactive voice, infants visual attention and affect declined. The sole loss of contingent vocal cues did not lead to a comparable still-face response. Thus, our findings supported the original findings by Gusella et al. (1988) in that the voice did not contribute to the still-face effect. These results suggest that the still-face effect is in fact due to a still-*face* not a "still-voice".

This raises the question as to why vocal information, which is fundamental to infants in other social contexts such as social referencing (Mumme, Fernald, & Herrera, 1996), did not contribute to the still-face effect. At the transition between the normal interaction and the still-face period, social contingency and reciprocity suddenly, and *without* any apparent reason, cease. This not comprehensible and unpredictable maternal behavior is stressful to the infant, leading to the still-face response. However, when contingent vocal overtures of an otherwise not visible social partner stop, it could have had several reasons, albeit not immediately perceivable to the child, but nevertheless warranted (e.g., the mother's attention could have temporarily been diverted elsewhere). Thus, the infant might consider this scenario to be less a breach of normal social-interactional conduct and hence, no still-face response is exhibited.

Summary Dyadic Interactions (Research Paper 7-8)

Responsive and reciprocative dyadic face-to-face exchanges are prominent during the first months of life. Much is learned in such intimate interactions, in which infants echo the affects, feelings, and emotions of their social partner. It is believed that this gives them a sense of shared experiences (Rochat, 2001). The still-face paradigm has been used to investigate infants' social understanding and expectations in face-to-face exchanges since several decades now. Our own research employing this procedure demonstrates that a still-face response is not exhibited until about 1.5 months after birth (research paper 7) and that the interactive face plays a crucial role in eliciting this response (research paper 8). It is around the second month of life that infants manifest major changes in the way they attend, perceive, and understand the physical and social world. For instance, the first socially elicited smile emerges around this time. Thus, it is not surprising that infants should also react negatively to the violation of natural dyadic exchanges. This, and other key developmental milestones, are believed to mark the end of the newborn phase and a general readiness on the part of the infant to interact with the world around them.

Triadic Interactions

The infants' world does not only contain people but also objects. As infants' body control and exploratory skills mature, they pay increasing attention to physical objects. Thus, they expand their world and attend not only to people encountered in intimate one-to-one social relationships but also to objects. Infants in their first half year of life are often observed to engage with objects in a self-absorbed way. However, at one point in development, infants start to engage with objects in conjunction with other people. This three-way interaction between a child, a social partner, and an object or event in the environment is called a triadic interaction. Aspects of this critical social exchange were investigated in research paper 9 and 10.

Infants do not only share experiences with others through face-to-face dyadic interactions but also through triadic interaction, where the shared experience is in reference to an entity in the environment. The most widely studied triadic exchange is joint attention. In joint attentional engagement, the child and the social partner attend simultaneously to the same object or event. Joint attention also involves both social partners' awareness of the other's focus to the external object or event. Infants typically exhibit this by alternating their looks between the object of mutual interest and the social partner. This critical social development usually occurs at around 9 months of age. Thus, toward the end of the first year of life, infants begin to share attention to object and events beyond the dyadic exchange.

Whereas an infant in a dyadic interaction needs to understand that the social partner engages with her/him, an infant in a triadic interaction needs to go beyond this realization and recognize that the social partner relates and communicates to her/him in reference to something else. It is believed that observed joint attention behavior indicates infants' understanding that one can share views and perspectives with others (Rochat, 2001;

Tomasello, 1999). The ability to jointly engage with others opens the door to cultural learning by means of teaching and imitation and is considered a crucial part of human social cognition.

Coordinated Affect in Visual Joint Attention (Research Paper 9)

Infants can jointly engage with a variety of social partners—their biological caregivers, siblings, peers, close and distant relatives, or even strangers. The nature of these social interactions are naturally different in various aspects (e.g., warmth, display of enthusiasm). Consequently, it is plausible that the display of joint engagement behavior does not only depend on the infant's age and social-cognitive development but also on the type of social partner. Indeed, differences in the display of coordinated joint engagement have been found as a function of social partner. Particularly, a study by Bakeman and Adamson (1984) revealed that infants displayed more joint engagement behavior while playing with their mothers than with peers. Moreover, affective expressions were likelier to occur when infants were in joint engagement with their mothers than with their peers. Thus, infants might be more inclined to share attention and affect with a familiar social partner such as their mother.

In the study of research paper 9, we further investigated the role that familiarity of the social partner plays in the production of joint engagement behavior and coordinated affect. For this, infants were longitudinally tested in triadic interactions with either their mother or a female stranger at 5, 7, and 9 months of age. Interestingly, at 7 months of age, but not earlier, did infants engage in more joint attention behavior with strangers than with their mothers. Furthermore, while infants were more likely to accompany their joint engagement behavior with affect as they got older, they did so whether they were in a triadic interactions with their mothers or a stranger. Moreover, the occurrence of joint engagement behavior increased with age in the stranger but not the mother play sessions. Thus, in the specific context of this study, infants displayed more coordinated joint engagement behaviors with a female stranger than with their mother but were equally inclined to display positive affect to the two different social partners.

Against the background of previous findings (e.g., Bakeman & Adamson, 1984), our results were surprising in that familiarity of the social partner did not increase infants' joint engagement behavior. It is possible that the combined effect of the female stranger's expansive social repertoire and the novelty she presented to the infants elicited heightened awareness and readiness to communicate in the children. Also, a different external focus (other than innocuous toys) might have revealed a different pattern. That is, play sessions with ambiguous toys might have elicited more joint engagement behavior toward the familiar social partner in an attempt to find reassurance regarding the toy's appropriateness. In any case, the differences found in the display of joint engagement behavior indicate that context may play a key role in the establishment and display of joint attention.

It has been suggested that joint engagement behaviors *accompanied* by positive affect may not be the same as other types of joint attention behaviors such as gaze following or requesting (e.g., Mundy, Kasari, & Sigman, 1992). When infants coordinate joint attention with positive affect it may index their active attempt to share not only attentional focus with others but also their emotional states towards the things in the world. Thus, it might be affect that puts "jointness" into joint engagement.

Infants' Object Processing in the Social Context (Research Paper 10)

So far I have discussed aspects of how infants perceive and understand the physical and social world separately. This separation generally mirrors the independent treatment of these two research areas in the field of infant studies. Although they have independently added to our knowledge of infants' perceptual and social development, there is little research combining these two areas of investigation. Thus, we know relatively little about the influence of social-environmental factors on infants' perception of the physical world. While past research has largely ignored this issue, it was the focus of research paper 10.

Social-environmental factors have a dramatic influence on infants' social-cognitive skills and behaviors such as declarative gestures (e.g., Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004), gaze following (e.g., Flom & Pick, 2005), or language learning (e.g., Tomasello & Todd, 1983). Based on this background, it seems plausible that social-environmental factors also affect infants' perception of the object world. Some empirical findings support this assumption. For example, 4-month-old infants' level of information processing and subsequent discrimination abilities were related to maternal behavior during play sessions (Miceli, Whitman, Borkowski, Brautgart-Rieker, & Mitchell, 1998). Moreover, data from behavioral and neurological research suggest that an adult's gaze guides infants' attention and facilitates information processing in the cued location (e.g., Reid & Striano, 2005). Thus, social-environmental factors not only influence infants' own social behavior, but also infants' processing of the physical world.

As infants get older, they often incorporate social partners into their exploration of the object world. Within these triadic play sessions, the social partner's behavior can range from enthusiastic involvement to apathetic disinterest (e.g., depressed mother). We were interested in the social factors that facilitate or impede infants' visual object processing within the triadic relation of self, other, and object. For this, we employed the habituation-novelty paradigm and familiarized infants to an object within different social contexts. Object processing was subsequently assessed by infants' ability to discriminate the habituation object from a novel one. As mentioned before, a novelty preference is taken to index full processing of the before seen, familiar object. We first examined whether 9- and 12-month-old infants' ability to process object information is differentially affected by social situations in which an adult social partner engages jointly with the infant and their object of mutual interest, compared to non-social situations in which no social partner is present.

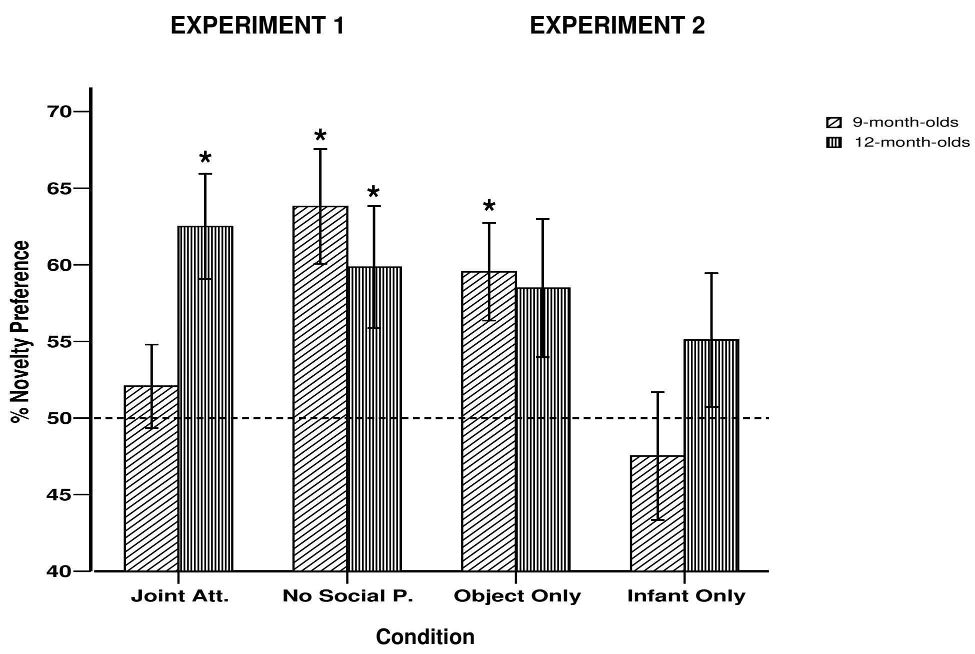


Figure 8: *Results of research paper 10. Asterisks indicate significant above 50% chance-level performance.*

As can be gleaned from Figure 8, both 9- and 12-month-olds were able to discern a novel object from a previously seen one when tested in a standard discrimination task (see Fig. 8; Experiment 1, *No Social Partner*). However, the younger age groups' discrimination abilities were impeded by the social context (evidenced by their null preference), while 12-month-olds revealed novelty preference scores indicative of full stimulus processing (see Fig. 8; Experiment 1, *Joint Attention*). The results of a subsequent experiment indicated that it were especially the social partner's infant-directed looks that impeded infants' ability to process the object (see Fig. 8; Experiment 2, *Infant Only*). In particular, in this condition, the social partner only looked at and engaged with the infant and ignored the object within the triadic context. In contrast, when the adult social partner only focused on the object of mutual interest and refrained from directing looks towards the infant, infants' discrimination abilities were strong during the test phase, indicating adequate object processing (see Fig. 8; Experiment 2, *Object Only*).

As infants grow older, they become more efficient information processors. This is not only true for the physical world in general but also for the social world. The findings of the study in research paper 10 suggest that with age, infants also grow more competent in their ability to process objects *within* natural social contexts (Experiment 1). As mentioned earlier, in a triadic interaction the infant must go beyond processing object- or event-related information and additionally needs to encode information about the social partner (e.g., communicative references, intentions, emotions). Naturally, this puts a higher strain on mental resources than solitary infant-object explorations or face-to-face dyadic interactions.

In research paper 7 and 8 we, as well as other researchers before us, demonstrated that infants become distressed when natural interpersonal interactions are violated. Similarly, it is plausible that by 12 months of age, infants have come to expect the social partner to behave in a certain way in triadic interactions. Consequently, they are perturbed by ambiguous situations in which the social partner does not act according to the protocol they learned to appreciate (e.g., looks only at the infant or only at the object as was the case in Experiment 2 of research paper 10). It is possible that, when faced with such a confusing triadic situation, the infant's attempt to understand the social partner's strange behavior takes precedence which, in turn, negatively interacts with processing the object presented within the triadic interaction.

In the real world, objects are very seldom processed devoid of any context. We often engage with and learn about them within social interactions. The results of research paper 10 reveal that the processing and learning about objects within a social context does not take place in a vacuum but is sensitive to the social-interactional factors that prevail.

Summary Triadic Interactions (Research Papers 9-10)

The dynamics of face-to-face dyadic interactions change dramatically when infants start to incorporate external references into their social exchanges. In two studies, we demonstrated that infants readily engage in joint attention behaviors with people other than their immediate caregivers (research paper 9) and that learning within the social context depends not only on the age of the child, but also on the social partner's interactional style (research paper 10). Engaging appropriately in triadic interactions is believed to be a giant step in social-cognitive development. Without this developmental milestone, infants could not learn from and imitate others. Thus, joint engagement serves specific functions important for skills such as language and theory of mind. Indeed, the shared social realities of everyday life cannot be constructed without joint engagement skills.

General Discussion of Dyadic and Triadic Interactions in Infancy

From birth on, infants are tuned to their social world whether they show this with their preference for human faces or their readiness to communicate. The results of research paper 7-10 suggest that from an early age on, infants actively partake in social exchanges. While these exchanges first revolve around intimate face-to-face interactions, they soon incorporate external references which makes social interactions involve topics other than the adult-infant pair themselves. Dyadic interactions are enjoyable and important to the infant. Much is learned about the self and others in this context. However, with increasing locomotive independence, infants are driven to explore the world around them more autonomously. The reassurance they get from close face-to-face social exchanges and the pull towards object exploration and away from caregivers might at first pose a dilemma to the young infant. Thus, object exploration and social proximity might become increasingly incompatible. It has been suggested that infants solve this dilemma by incorporating social partners into their exploration of the object world (Rochat, 2001). Thus, the constrained face-to-face interactions are opened up in order to learn about and explore the environment at large.

Interestingly, when infants start to engage in organized interactions between self, others, and jointly attended objects, their behavior in face-to-face dyadic interactions also changes. Where younger infants are perturbed and stressed by the sudden dispositional change of the social partner (evidenced by, for example, decreased visual attention), older infants try to reengage the partner by vocalizing or touching the still-faced social vis-à-vis (e.g., Rochat, 2001). Thus, infants in the second half of their first postnatal year will initiate and shape the social exchange with others in dyadic and triadic interactions.

The importance of infants' participation in dyadic and triadic exchanges for the infant's general development can not be stressed enough. Faulty joint attention exchanges early in development (often displayed by children with autism) can lead to later difficulties in interpreting and reading other peoples' minds and intentions. Indeed, much about self, others, objects, and conventional systems such as language is learned within the social context of dyadic and triadic interactions. Thus, aside from being enjoyable for both infant and social partner, they serve important functions for social and cognitive development.

Concluding Remarks

In 10 research papers, I explored the physical and social world of infants. Within the realm of visual object and face perception, I examined infants' sensitivity to various kinds of spatial relational information. The results suggest that infants, like adults, are sensitive and selectively attentive to ecologically relevant properties in objects and higher-order information in human faces. Thus, infants are sensitive to some of the same building blocks that are part of the mature human's visual system. Within the field of social cognition, I investigated aspects of dyadic and triadic interactions, both of which are thought to play an important role in infants' social and cognitive development. Together with my colleague, I demonstrated that from an early age on, infants actively participate in social exchanges and are alert to the social-interactional factors that prevail.

While this work made valuable contributions to the field of object and face perception as well as social cognition in infancy, the quest of understanding the physical and social world of the infant is far from over. While my colleagues and I were able to answer several important questions concerning infants' perceptual and social development, many still remain. At the very least, I hope I was able to convince the reader that infants perceives their world as structured and ordered and *not* as was once suggested by William James (1890), like a "blooming, buzzing confusion".

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REPORT

Figural goodness, stimulus heterogeneity, similarity and object segregation in infancy

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Abstract

The segregation of objects from other objects in visual arrays is a fundamental function of our visual system. Research suggests that adults' detection of a target among nontargets is affected by the heterogeneity of array elements and the resulting changes in target–nontarget and nontarget–nontarget similarities. We examined the effects of heterogeneity and similarity on object segregation in infancy. In Experiment 1, 5.5-month-olds detected a misoriented element in an array when the array elements were spatially arranged in a 'good' configuration but not when they were arranged in a 'poor' configuration. In Experiment 2, infants detected a vertical line in a homogeneous array of 55° or 125° lines, but failed to do so in a heterogeneous array of 55° and 125° lines. Thus, heterogeneity in both the arrangement and identity of array elements affected infants' discrepancy detection. Because the average target–nontarget similarity was the same in the two conditions of Experiment 2, the results also indicated that nontarget–nontarget similarity independently affects discrepancy detection in infancy. These results are consistent with models of object segregation by adults, and suggest that stimulus heterogeneity and similarity have analogous effects on object segregation at 5.5 months of age and in adulthood.

Fundamental visual functions such as object recognition begin with the segregation of objects from their surroundings (Salapatek, 1975; Marr & Nishihara, 1978; Beck, 1982; Julesz, 1984; Needham, 1998; Needham, Baillargeon & Kaufman, 1997). For several decades now, researchers have examined object segregation by using visual search studies in which adult participants search for a discrepant object in an array of objects (e.g. Beck, 1966; Treisman & Gelade, 1980). The current study was designed to investigate the nature of discrepancy detection in infancy. It examined the effects of heterogeneity and grouping of array elements on 5.5-month-olds' detection of a discrepant object.

Many current models of object perception predict that the speed and accuracy of finding a discrepant element in an array will be deleteriously affected by the heterogeneity of the surrounding elements (e.g. Treisman, 1988, 1993; Duncan & Humphreys, 1989, 1992; Wolfe, 1994). Consider, for instance, Treisman's (1993) feature integration theory. This theory assumes that elements in visual arrays are represented by activity in retinotopically organized feature-specific neuronal 'maps'. Activity differentials in these maps determine the discriminability of an object in the array. Thus, for instance, feature integration theory assumes that the greater the activity in a particular feature map in relation to other maps, the faster the detection of an object with that feature in the array. It therefore follows that the greater the heterogeneity of elements in an array, the greater the activity in different feature maps, which would decrease the signal-to-noise ratio and thereby reduce the speed/accuracy of detection of the relevant target object in an array.

While Treisman's model and other models (see, for example, Wolfe, 1994) predict the effects of distractor heterogeneity on the detection of an object in an array, Duncan and Humphreys' (1989, 1992) attentional engagement model of visual search by adults specifically addressed the role of heterogeneity of array elements. According to this model, heterogeneity affects discrepancy detection because the ease of detection of a discrepant object (target) in an array is a function of the

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extent to which it acquires attentional strength relative to the other objects in the array (nontargets). For instance, a target will acquire attentional strength to the extent that it is dissimilar from the nontargets in the array. Moreover, a discrepant object acquires *relative* attentional strength to the extent that the nontargets are perceptually grouped together. This is because, according to Duncan and Humphreys, there is 'spreading suppression' of attentional strength of the distractors in the display, and this suppression is a function of the similarity among these objects. In other words, the nontarget objects in an array acquire relative 'negative' attentional strength from each other to the extent that they are similar to each other and are grouped together.

Thus, according to Duncan and Humphreys (1989, 1992), two types of similarity are important in determining the ease with which adults detect a discrepant object in an array. One type of similarity involves that between the target and the surrounding nontarget objects (target–nontarget similarity). That is, objects that are less similar to the surrounding objects should be more easily discriminated than those that are more similar. The second kind of similarity involves the similarity among the nontargets that surround the target in an array (nontarget–nontarget similarity). The more similar these objects are to each other (Duncan & Humphreys, 1989, 1992; also see Farmer & Taylor, 1980; Bundesen & Pedersen, 1983) or the easier it is to group these objects based on their arrangement (e.g. Treisman, 1982; Humphreys, Quinlan & Riddoch, 1989), the easier it should be to discriminate the target because the nontargets 'suppress' each other's attentional strength more when they are similar to each other. In summary, Duncan and Humphreys' (1989, 1992) model and empirical findings indicate that changes in target–nontarget and nontarget–nontarget similarity relations engendered by changes in heterogeneity affect adults' detection of a discrepant object in an array.

The question then arises as to how heterogeneity and changes in similarity relations affect object segregation in infancy. For instance, does heterogeneity of arrays deleteriously affect object segregation in infancy in the same way as it does in adulthood? Also, do both kinds of similarity relations, target–nontarget and nontarget–nontarget, affect infants' performance the same way as they do adults' performance? Given the central role played by these factors in models of adult object segregation and recognition, we believe that answers to these questions will contribute to the understanding of the development of basic object segregation and recognition processes in infancy.

In the current experiments, we examined the effects of heterogeneity of array elements on 5.5-month-olds' detection of a discrepant object. Different arrangements of the same pattern elements might affect discrepancy detection. Similarly, the presence of two or more types of pattern elements versus one type of element in an array might affect discrepancy detection. Thus, heterogeneity can be induced by variability in either the arrangement or the identity of array elements. We examined both kinds of heterogeneity effects. We also examined whether nontarget–nontarget similarity affects infants' discrepancy detection independently of target–nontarget identity.[1] Recall that, according to Duncan and Humphreys (1989, 1992), the more similar nontarget objects are to each other, the easier it is for them to be grouped together, which would lead to greater *spreading suppression* among the members of this group and result in the easier detection of the discrepant element. In the current study, we examined whether, as predicted by Duncan and Humphreys' model, decreasing nontarget–nontarget similarity interferes with infants' detection of a novel object in an array.

In a series of studies, Dannemiller and his colleagues examined the effects of array heterogeneity on the detection of a discrepant object by infants (Dannemiller & Nagata, 1995; Nagata & Dannemiller, 1996; Dannemiller, 1998). In these studies, 3.5-month-old infants were typically exposed to a moving colored bar amidst one or more stationary colored bars, and an adult observer determined the left–right location of the moving object based on the infants' looking behavior (forced-choice preferential looking procedure). Dannemiller and his colleagues found that heterogeneity affects infants' discrepancy detection at least under certain conditions. Dannemiller and Nagata (1995), for instance, found that increasing the heterogeneity of the stationary bars by varying their colors decreased the speed of responding by the adult observer (and, by inference, by the infants).

While the research by Dannemiller and Nagata examined the effects of heterogeneity on infants' detection of a moving target, the current study examined whether heterogeneity affects infants' detection of a

[1] We chose not to examine target–nontarget similarity because prior research already indicates that this factor does affect the discrimination of the discrepant object by infants (e.g. Bhatt, 1997; Bhatt, Bertin & Gilbert, 1999; Bertin & Bhatt, 2001). For instance, Bhatt *et al.* (1999) and Bertin and Bhatt (2001) found that infants discriminate discrepancies based on fundamental features more easily than those based on feature conjunctions. Objects that differ from surrounding objects on the basis of features are more dissimilar from the surrounding objects than those that differ on the basis of feature conjunctions (miscombinations of features belonging to different surrounding objects). These results indicate that the similarity between target and nontargets is important in the discriminability of objects.

stationary target. Further, while Dannemiller and his colleagues manipulated heterogeneity using changes in the number and colors of stationary bars surrounding the moving bar target, in the current study we used variation in orientation and arrangement of shapes. Also, it is not clear whether the heterogeneity manipulations in the studies by Dannemiller and his colleagues were such that the target–nontarget similarity was unaffected. That is, it is not clear whether their studies examined the role of nontarget–nontarget similarity without affecting the target–nontarget similarity. In the current study, especially in Experiment 2, we manipulated nontarget–nontarget heterogeneity without affecting the average target–nontarget similarity. Thus, we were able to examine the role of distractor heterogeneity *per se*, independent of changes in target–nontarget similarity.

Experiment 1

Donnelly, Humphreys and Riddoch (1991) reported that the spatial arrangement of array elements affects adult humans' detection of a discrepant element in an array. Specifically, Donnelly *et al.* found that the latency to detect a target element was not affected by the number of other elements in an array if the array elements were arranged into a 'regular' (symmetrical) form. In contrast, the latency increased with increasing numbers of nontarget array elements if the array elements were arranged to have an 'irregular' (asymmetrical) form. In the current experiment, we examined whether manipulating the ease of grouping of array elements by varying their spatial arrangement would affect the detection of a discrepant element in infancy.

Note that, according to Duncan and Humphreys' (1989, 1992) model of attentional engagement, interfering with the grouping of nontarget elements should hinder the detection of the target element. Grouping can take place on the basis of many stimulus factors, such as continuation between line endings, closure or shape symmetry (e.g. Banks & Prinzmetal, 1976; Prinzmetal & Banks, 1977; Donnelly *et al.*, 1991). Thus, interfering with grouping by manipulating these stimulus factors should affect the ease of detection of a discrepant element in an array.

Prior research indicates that infants are sensitive to the arrangement of pattern elements (e.g. Van Giffen & Haith, 1984; Humphrey, Humphrey, Muir & Dodwell, 1986; Ghim, 1990; Quinn, Burke & Rush, 1993). Humphrey *et al.* (1986), for instance, habituated 4-month-olds to 'good', 'medium' or 'poor' forms, with the 'goodness' of a pattern defined by the number of axes of symmetry possessed by the pattern. Infants habituated more quickly to the 'good' and 'medium' patterns than to the 'poor' pattern. Similarly, Quinn *et al.* (1993) found that 3-month-olds can organize visual patterns based on the lightness similarity of elements.

In the current research, we examined whether it is easier for infants to discriminate a misoriented element if the array elements form a 'good' form than if they do not. In other words, we examined whether infants discriminate a discrepancy that leads to a change in a 'good' form pattern but do not discriminate a comparable discrepancy in a pattern that does not constitute a 'good' form pattern. Specifically, as can be seen in Figure 1, infants were familiarized to a pattern containing four elements arranged into a 'good' form (a square) or a 'poor' form. Then, infants were tested with a pattern in which one of the array elements was rotated 180°. If infants detected a change in the 'good' form

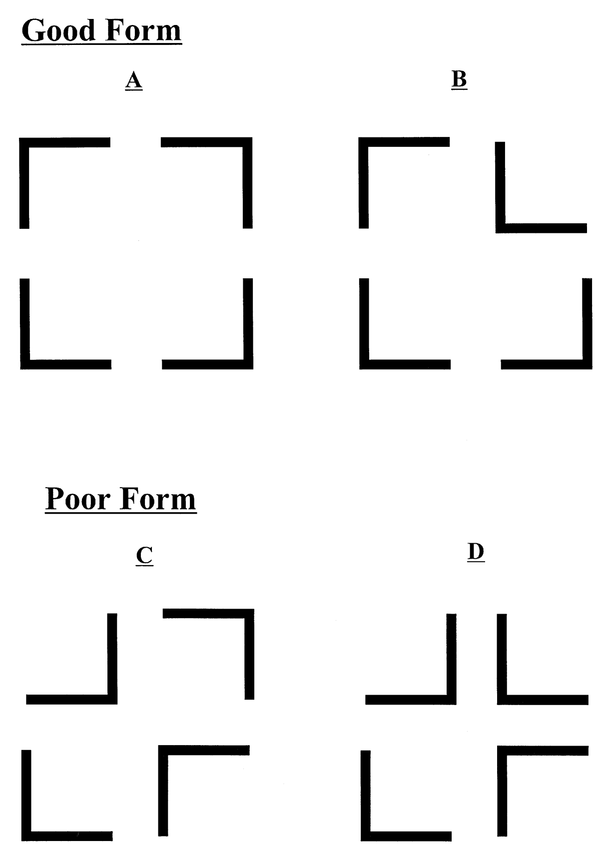

Figure 1 *Examples of the test stimuli used in Experiment 1. Infants were familiarized with patterns of the sort shown in (A) and (C) before being tested. Note that the individual elements in the corresponding patterns of the two conditions are the same, and that the patterns differ only in the arrangement of these elements.*

pattern but not in the 'poor' form pattern, then it would suggest that differences in the arrangement of pattern elements can affect the discriminability of a discrepant element in the pattern.

We used a familiarization–novelty preference paired-comparison procedure to examine this issue (e.g. Fagan, 1970; Bhatt & Waters, 1998). Infants were familiarized to two identical copies of an array of elements and then tested with an array containing familiar elements paired with another array containing a novel misoriented element amidst familiar stimulus elements. If infants looked longer at the array with the discrepant element than at the familiar array during the test, then it was inferred that the infants had detected the discrepant object. If, on the other hand, infants did not exhibit this novelty preference, then it was inferred that the infants had failed to detect the novel discrepant element.

Method

Participants

Thirty-two 5.5-month-olds (14 females, 18 males; mean age 166.25 days; SD = 19.97) participated in this study. Infants in this and the following experiment were recruited via public birth announcements and they were predominantly Caucasians from middle-class backgrounds. An additional six participants were excluded from the study for crying ($n = 3$) or for not sampling both stimuli during the test ($n = 3$).

Stimuli

The stimulus patterns used in this experiment contained four array elements, each of which contained two black lines angled at 90° from each other (Figure 1). From the infant's point of view, each of the four array elements subtended $4.58° \times 4.58°$ and the whole pattern subtended $12.1° \times 12.1°$. During familiarization, infants in the *good form* condition were exposed to a pattern in which the array elements were arranged to have a 'good' form (square); infants in the *poor form* condition were exposed to a pattern in which the array elements were arranged so that the pattern was *not* a 'good' form (Figure 1). During the test, infants in both conditions were tested for their preference between a familiar pattern and another pattern that contained a single element that was misoriented (Figure 1). Four different versions of the stimuli were used in each condition, such that the discrepant element was either in the top-right, bottom-right, top-left or bottom-left corner of the pattern.

Apparatus

The apparatus used was a modified version of the apparatus used by Fagan (1970). It consisted of a hinged, three-sided stage that contained two compartments to hold stimulus cards. The whole apparatus was painted black. A 60 W fluorescent bulb, hidden from the infant's view by an overhanging shelf, illuminated the stage. The infant was exposed to the stimulus cards placed in the display compartments when the stage was closed; the infant was exposed to the experimenter and could not see the stimulus cards when the stage was open. Participants were seated about 30.50 cm in front of the display panel (the closed stage) in an infant seat that was inclined at 45° to correspond to the angle of the stage. A 0.625 cm peephole in the middle of the display screen allowed the recording of infants' look direction using a Pro Video CVC-120PH pinhole camera and a Sony GV-A500 portable video recorder.

Procedure

Experimental sessions were conducted in infants' homes at a time when their parents indicated that they were likely to be alert. The session began with the portable apparatus being wheeled over the infant who was seated in an infant seat, keeping the infant's head centered with respect to the midline of the display stage. The test session consisted of six 15 s familiarization trials, followed by two 10 s test trials. Each familiarization and test trial began with the display stage open and the experimenter attracting the infant's attention to the middle of the display stage. Once the infant looked at the experimenter, the stage was closed to display two patterns to the infant, one on the left and the other on the right. The direction of the infant's gaze was recorded by the camera and VCR.

During familiarization trials, infants were exposed to two identical patterns (Figure 1, panels A and C). During the test trials, infants were tested for their preference between a familiar pattern versus another that contained a misoriented element (Figure 1). The left–right positioning of the pattern with the discrepant element on the first test trial was counterbalanced across participants in each group; the position of this novel pattern was reversed on the second test trial.

Infants were randomly assigned to the good form and the poor form groups. As noted above, infants in the good form group were tested with a 'good' form of familiar elements paired with another pattern that contained a single misoriented element among familiar elements (Figure 1). Infants in the poor form group were tested with a 'poor' form familiar pattern paired with another containing a single misoriented element amidst the familiar elements (Figure 1).

Infants' performance was coded off-line by an experimenter who was unaware of infants' group assignment and of left–right positioning of the novel pattern during the test trials. The videotape was slowed to 20% of normal speed for coding. The performance of eight infants was coded by another naïve experimenter, and we determined inter-observer reliability by examining the correlation between the trial-by-trial looking times to the left and to the right coded independently by each observer for each infant. The average Pearson correlation between the two observers was 0.98 (SE = 0.28) during familiarization trials and 0.96 (SE = 0.51) during test trials.

Results and discussion

Preliminary analyses revealed that the infants' gender did not significantly affect their looking times during the familiarization trials or their preference during the test trials. Thus, the data were collapsed over this variable in subsequent analyses. Table 1 displays infants' looking times during the familiarization trials. A trials (1–2, 3–4, 5–6) $\times$ group (good form, poor form) analysis of variance (ANOVA) revealed only a trials main effect, $F(2, 60) = 14.14$, $p < 0.01$. This indicates that infants in both conditions reached an equivalent level of familiarization before being tested.

As is customary in studies that employ the procedure used in this experiment (e.g. Quinn *et al.*, 1993; Behl-Chadha & Eimas, 1995; Bhatt & Waters, 1998), we computed a novelty preference score to examine infants' performance during the test trials. This score was computed by dividing the duration of looking toward the novel pattern during the two test trials by the total duration of looking toward both patterns during the test and by multiplying this proportion by 100 to get a percent preference score. A mean group score that was greater than 50% was assumed to indicate that the infants preferred to look at the side with the novel discrepant element. That is, a score greater than 50% was assumed to mean that the infants in this group discriminated the discrepancy. In contrast, a group mean score that was not different from 50% was assumed to indicate that the infants failed to detect the discrepant element during the test.

Table 1 *Mean (and standard error) of fixation duration during familiarization trials and percent preference for the array with the single novel element during test trials in Experiment 1*

Familiarization (s)			
	Trials 1–2	Trials 3–4	Trials 5–6
Good form	5.20 (0.65)	4.69 (0.62)	3.22 (0.26)
Poor form	5.92 (0.64)	5.24 (0.56)	4.27 (0.59)

Novelty preference during test (%)				
	M (SE)	*N*	*t* (vs chance)	*p* (two-tailed)
Good form	59.44 (3.61)*	16	2.61	<0.02
Poor form	48.22 (3.86)	16	−0.46	>0.05

Note: Asterisks indicate a mean novelty preference score that is significantly greater than the chance level of 50%.

Table 1 displays the novelty preference scores exhibited by the two groups of infants during the test. As can be seen, infants in the good form group discriminated a change during the test, whereas the infants in the poor form group did not. Infants in the good form group exhibited a novelty preference score that was significantly greater than the chance level of 50%, $t(15) = 2.61$, $p < 0.02$, two-tailed, whereas infants in the poor form group failed to do so, $t(15) = -0.46$, $p > 0.05$. Moreover, the novelty preference score of the good form group was significantly greater than the novelty preference score of the poor form group, $t(30) = 2.12$, $p < 0.05$, two-tailed.

These data indicate that infants discriminated a misoriented array element when the discrepancy modified a good form but not when it modified a poor form. Thus, consistent with Duncan and Humphreys' (1989, 1992) model of attentional engagement, interfering with grouping by modifying the arrangement of elements in a pattern deleteriously affected infants' discrimination of a misoriented element in an array.

These results are consistent with prior reports indicating that infants are sensitive to arrangements of pattern elements (e.g. Van Giffen & Haith, 1984; Humphrey *et al.*, 1986; Ghim, 1990; Quinn *et al.*, 1993). However, to our knowledge, no prior study has examined whether infants are sensitive to a change in a single element in a pattern that comprised a good form versus one that comprised a poor form.

Note that the same array elements were present in the good forms and in the poor forms used in this experiment, albeit in different arrangements (Figure 1). Thus, it could be argued that the average similarity between the misoriented element and the other elements in the array must have been the same in the two conditions. It follows, therefore, that it was solely a difference in the nontarget–nontarget similarity (and not a difference in the target–nontarget similarity) that led to the different performance in the two conditions.

However, it could also be argued that the target–nontarget similarity relationships in the two conditions are hard to assess because the holistic patterns engendered by the arrangement of pattern elements were different in the two conditions. Thus, it is not clear whether the simple manner of determining similarity based on relations among the constituent elements captures the role of similarity in this study. In other words, discrepancy detection might have occurred at a level of processing that might be different from that affected by the similarity relations among the constituent elements of these holistic images. Therefore, it might be argued that the results of Experiment 1 do not clearly indicate the role of nontarget–nontarget similarity independent of the role of target–nontarget similarity. One of the goals of Experiment 2 was to further examine this issue.

Experiment 2

This experiment was motivated by two considerations: (a) to extend the generality of the results obtained in Experiment 1 by examining whether heterogeneity induced by variation in the identity of array elements affects discrepancy detection in the same manner as did the heterogeneity induced by changes in the arrangement of elements in Experiment 1, and (b) to examine whether nontarget–nontarget similarity affects object segregation independently of target–nontarget similarity.

To address the first issue noted above, we contrasted performance in a condition in which infants had to discriminate a vertical line among a homogeneous collection of oblique lines versus a condition in which infants had to discriminate the same target among a heterogeneous collection of oblique lines. If heterogeneity induced by the variability in the identity of array elements also affects discrepancy detection in infancy, then infants should have difficulty detecting the vertical line when it is surrounded by a heterogeneous collection of oblique lines but not when it is surrounded by a homogeneous collection.

To address the second issue noted above, we compared the performance of infants in two conditions that differed in nontarget–nontarget similarity but not in average target–nontarget similarity. Thus, we were able to assess the independent contribution of nontarget–nontarget similarity to the detection of an object in an array. Specifically, we examined infants' sensitivity to a discrepant vertical line (90° orientation) amidst a homogeneous collection of lines oriented at either 55° or 125° (*homogeneous* condition) versus their sensitivity to a discrepant vertical line amidst a heterogeneous collection of lines oriented 55° *and* 125° (*heterogeneous* condition; see Figure 2). Note that the average discrepancy between the target, the 90° line and the nontargets in both conditions was 35° of orientation. However, in the heterogeneous condition two different lines comprised the nontargets (lines oriented at 55° *and* 125°), whereas in the homogenous condition only one of these kinds of lines comprised the nontargets (lines oriented at 55° *or* 125°). Thus, heterogeneity of nontarget elements was manipulated without changing the average target–nontarget similarity.

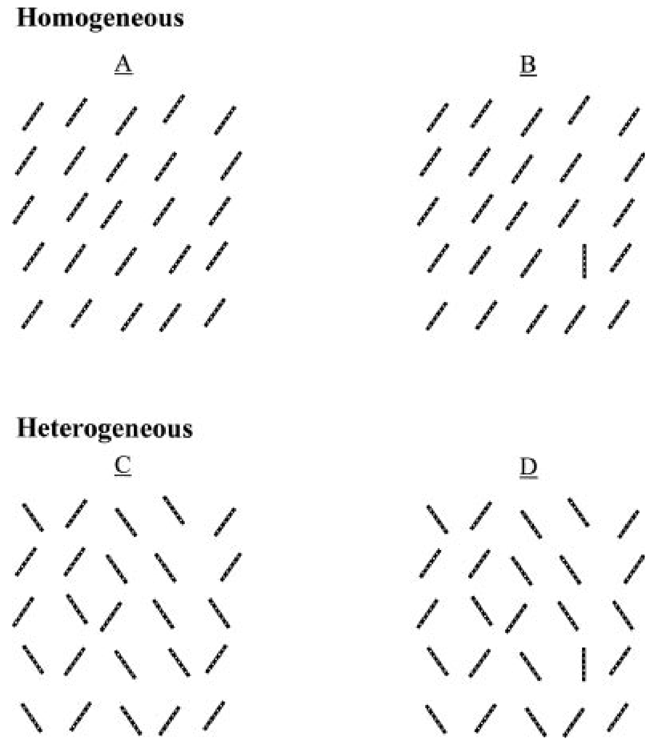

Figure 2 *Examples of the test stimuli used in Experiment 2. Infants were familiarized with patterns of the sort shown in (A) and (C) before being tested. For half of the infants in the homogeneous condition, the nontarget elements were oriented at 55°; for the other half, these elements were oriented at 125°. Note that the average target–nontarget similarity is 35° in both conditions.*

An infant-control habituation procedure was used in this study (Horowitz, Paden, Bhana & Self, 1972). This procedure was similar to the procedure used in Experiment 1 except that familiarization trials continued until infants met a criterion level of habituation. That is, instead of a fixed number of familiarization trials (six 15 s trials in Experiment 1), familiarization continued until a criterion level of habituation was achieved. This change in procedure was in response to the concern that infants might habituate to different levels in the homogeneous condition versus the heterogeneous condition if only a limited number of trials were used. By extending familiarization until a criterion level of habituation was reached, we were able to ensure that infants in the two conditions were tested only after an equivalent level of habituation was reached.

Method

Participants

Twenty-four 5.5-month-olds (12 males, 12 females; mean age 172.63 days; SD = 8.35), recruited in the same manner as infants in Experiment 1, participated in this study. Data from an additional 12 infants were not included for crying ($n = 8$) or for not sampling both test stimuli ($n = 4$). We used fewer subjects in this experiment than in Experiment 1 because we expected less performance variability and more power to result from the use of the infant-controlled habituation procedure in this study.

Stimuli

The stimuli consisted of 5×5 arrays of patterned lines printed on white card stock (Figure 2). Each line element subtended approximately 2.4° and each pattern subtended $22.5° \times 22.5°$ from the infant's point of view. The position of each individual element was randomly displaced 1.18° vertically and/or horizontally to avoid any accidental alignments. Half of the infants in the homogeneous condition were habituated to a pattern containing lines all oriented at 55°; the other half were habituated to a pattern containing lines all oriented at 125°. All infants in the heterogeneous condition were habituated to a pattern containing 12 lines oriented at 55° and 13 lines oriented at 125°. After habituation, infants were tested on two patterns, a familiar pattern paired with another that contained a single vertical line. The position of the discrepant element was counterbalanced across infants, so that it was either at the top left or the bottom right of the test pattern.

Apparatus

The apparatus was the same as that used in Experiment 1.

Procedure

As noted above, an infant-controlled habituation procedure was used. That is, unlike in Experiment 1, the duration and the number of familiarization trials were determined by the looking behavior of individual infants. Each familiarization trial continued until an infant looked away for 4 s consecutively or after a maximum of 60 s had elapsed. (We used a 4 s 'look away' rather than the typical 1 or 2 s because pilot studies indicated that the shorter durations were insufficient to ensure adequate habituation under these conditions.) Also, familiarization trials were repeated until the mean looking time during three consecutive trials was less than half of the mean looking time during the first three familiarization trials. This procedure thus ensured that infants in both the homogeneous and heterogeneous groups had habituated to the same extent before being tested. The test trials were conducted in exactly the same manner as the test trials in Experiment 1. Also, as in Experiment 1, infants' performance was coded off-line by an experimenter who was unaware of infants' group assignment and of the left–right positioning of the novel pattern during the test trials.

Results and discussion

Preliminary analyses revealed that the infants' gender did not significantly affect their looking times during the familiarization trials or their preference during the test trials. Thus, the data were collapsed over this variable in subsequent analyses. Table 2 details the trials to criterion, the total fixation durations, and the looking times during the first three and the last three habituation trials for the two groups. Analyses (t tests and an ANOVA) revealed that none of the differences between the two groups was statistically significant. These results suggested that the two groups had reached an equivalent level of habituation prior to being tested.

Table 2 indicates the mean novelty preference scores exhibited by infants in the two conditions. Infants in the homogeneous condition discriminated the change in the novel test pattern. Their mean novelty preference score was significantly greater than the chance level of 50%, $t(11) = 2.58$, $p < 0.03$, two-tailed. In contrast, the mean novelty preference score of infants in the heterogeneous condition was not significantly different from the chance level of 50%, $t(11) = -0.75$, $p > 0.05$. Also, there was a

Table 2 *Mean (and standard error) of number of trials to criterion, fixation duration during habituation, and percent preference for the array with the single novel element during test trials in Experiment 2*

Habituation	Number of trials to criterion	Total fixation (s)	First three trials (s)	Last three trials (s)
Homogeneous	7.00 (0.54)	85.84 (10.87)	19.73 (3.31)	6.78 (1.12)
Heterogeneous	6.83 (0.34)	93.72 (13.72)	20.97 (3.09)	7.64 (1.13)

Test performance: Preference (%) for array with single novel element	*M* (SE)	*N*	*t* (vs chance)	*p* (two-tailed)
Homogeneous	59.55 (3.71)*	12	2.58	<0.03
Heterogeneous	45.94 (5.42)	12	−0.75	>0.05

Note: Asterisks indicate a mean novelty preference score that is significantly greater than the chance level of 50%.

significant difference between the novelty preference scores exhibited by the two groups, $t(22) = 2.07$, $p < 0.05$, two-tailed.

Thus, infants detected a vertical line in a homogeneous pattern of lines oriented at either 55° *or* 125°. However, they failed to detect a similar discrepancy in a pattern containing a heterogeneous mixture of 55° and 125° oriented lines. These results indicate that (a) heterogeneity induced by variation in the identity of array elements affects discrepancy detection in infancy in the same manner as heterogeneity induced by the arrangement of array elements, and (b) nontarget–nontarget similarity affects discrepancy detection independent of target–nontarget similarity (because the latter similarity was the same in the two conditions of this experiment).

It should be noted that Treisman and Gormican (1988) found that an oblique among verticals 'pops out' for adults but a vertical among obliques does not. That is, in the former condition the latency to detect the oblique line is independent of the number of vertical distractors, whereas in the latter condition the latency to detect the vertical line increases with increasing number of oblique distractors. Previously, we have found that, under certain conditions, infants detect discrepancies that pop-out for adults but not those that do not (Rovee-Collier, Hankins & Bhatt, 1992; Bhatt, 1997; Quinn & Bhatt, 1998; Bhatt *et al.*, 1999; Bertin & Bhatt, 2001). However, in the current study, infants detected a vertical among obliques in the homogenous condition, thereby indicating there is no one-to-one correspondence between speed of processing (pop-out versus serial processing) in adulthood and discrimination or lack thereof in infancy.

General discussion

The current experiments revealed that (a) heterogeneity, induced by variability either in the arrangement (Experiment 1) or in the identity (Experiment 2) of array elements, interferes with infants' discrimination of a novel object in an array, and (b) heterogeneity that leads to a decrease in nontarget–nontarget similarity affects infants' discrepancy detection independently of variation in target–nontarget similarity.

Prior research indicates that many aspects of discrepancy detection in visual arrays, such as the relative difficulty of detecting featural versus conjunction-based discrepancies (e.g. Rovee-Collier *et al.*, 1992; Bhatt, 1997; Bhatt *et al.*, 1999; Bertin & Bhatt, 2001) and attentional engagement by objects that differ from the surrounding objects in terms of fundamental features (perceptual 'pop-out'; e.g. Rovee-Collier *et al.*, 1992; Colombo, Ryther, Frick & Gifford, 1995; Bhatt, 1997; Quinn & Bhatt, 1998; Bhatt *et al.*, 1999; but see Sireteanu, 2000), exhibit similar characteristics in infancy as in adulthood. The current research adds to this literature by indicating that heterogeneity of array elements and similarity relations have similar effects on object segregation in infancy as in adulthood. More generally, the current research adds to a growing body of evidence suggesting that many of the processes that underlie object segregation in adulthood are evident early in life (Bhatt, 1997; Needham *et al.*, 1997; Needham, 1998; Needham & Baillargeon, 1998; Bertin & Bhatt, 2001).

The results of the current experiments are consistent with a model of exogenous attention in infancy proposed by Dannemiller (1998). Dannemiller posited that competition for an infant's attention by multiple objects in a visual field is resolved by the relative salience of the objects, with the object with the highest relative salience ultimately garnering the infant's attention. Presumably, in the current experiments, heterogeneity of the nontarget elements led to increased competition for attentional strength, thereby leading to an absence of orienting toward the discrepant element during the test trials.

The results obtained in the current experiments are also consistent with the empirical findings by Dannemiller and his colleagues that nontarget heterogeneity affects the ease of detection of a discrepant moving object in an array (Dannemiller & Nagata, 1995; Nagata & Dannemiller, 1996; Dannemiller, 1998). The current studies extend these findings to stationary discrepant elements, to different features, to a different age group and to a different test procedure. Moreover, the current experiments involved two different kinds of grouping, one based on an arrangement of array elements that either did or did not lead to a 'good' form, and the other based on the variability in the arrangement of array elements.

The findings of the current study that ease of grouping of array elements affects the ease of infants' detection of a discrepant element in the array are also consistent with a number of models of adult object segregation (e.g. Treisman, 1992, 1993; Wolfe, 1994). In particular, these findings are consistent with Duncan and Humphreys' (1989, 1992) attentional engagement model of visual search, a key element of which is the proposal that nontarget–nontarget similarity affects target detection by adults.

As noted earlier, according to Duncan and Humphreys (1989, 1992), two kinds of similarity relations play a role in discrepancy detection, the similarity between the discrepant element and other elements in the array and the similarity among the nontarget array elements themselves. Prior research indicates that target–nontarget similarity does affect the ease of target detection (e.g. Bhatt, 1997; Bhatt *et al.*, 1999; Bertin & Bhatt, 2001). The current experiments established that nontarget–nontarget similarity also affects the ease of discrepancy detection, independent of target–nontarget similarity.

Recall that, according to Duncan and Humphreys (1989, 1992), increases in the nontarget–nontarget similarity increases the grouping of the nontarget elements, such that these elements gain more negative attentional strength from each other, which in turn increases the relative positive attentional strength of the target element. Thus, in the current experiments, grouping of nontargets in the heterogeneous conditions was presumably deleteriously affected in comparison to the homogeneous conditions. This presumably decreased the attentional strength contrasts between the target and nontarget elements in the heterogeneous conditions, resulting in lack of discrimination.

It should be noted that, while similarity relations might be able to account for the results obtained in the current studies, they may not be able to completely account for variation in infants' detection of discrepancies in visual arrays. Treisman (1991, 1992) has argued that similarity alone does not account for adults' performance on visual search tasks. Similarly, Bertin and Bhatt (2001) found that overall similarity relations between novel arrays and familiar arrays cannot account for differences in infants' detection of featural discrepancies versus those based on relations among features. Thus, similarity might not be able to account for all aspects of discrepancy detection in infancy. Nevertheless, the results of the current experiments indicate that heterogeneity and similarity do play similar roles in object segregation in infancy as in adulthood.

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Three-month-olds' sensitivity to orientation cues in the three-dimensional depth plane

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Abstract

Three-month-olds are sensitive to orientation changes of line drawings when they have a three-dimensional (3-D) interpretation and when the changes are defined by both 3-D depth and two-dimensional (2-D) picture plane cues [Bhatt, R. S., & Bertin, E. (2001). Pictorial cues and three-dimensional information processing in early infancy. *Journal of Experimental Child Psychology, 80,* 315–332]. In the current study, we examined whether 3-month-olds are sensitive to pictorial line junction cues that signal orientation changes solely in the 3-D depth plane. The results revealed that infants discriminated a misoriented elongated cube in an array when the stimuli contained both shading and lines (Experiment 2) but not when only lines depicted the elongated cubes (Experiment 1). Testing with comparable 2-D images revealed that, even in the presence of shading information, detection of orientation changes is specific to images that have a 3-D interpretation. Together, the results suggest that 3-month-olds are sensitive to pictorial line junction cues that signal orientation changes in the 3-D depth plane to adults provided that shading information is available and the images have a 3-D interpretation.

Keywords: Pictorial depth cues; Line-junction cues; Shading cues; Three-dimensional (3-D) perception; Infancy

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Introduction

The three-dimensional (3-D) structure of the world around us is perceived through many cues. For example, the visual system uses motion and binocular cues, such as motion parallax and retinal disparity, to derive 3-D spatial layout and structure. However, a sense of depth (albeit often less vivid) is also perceived when the observer and object are stationary, when the world is inspected monocularly, and when 3-D scenes are presented in photographs and pictures. Indeed, artists have developed a number of pictorial depth cues (e.g., linear perspective, interposition, texture gradient, shading) that convey depth and spatial layout to the observer. Presumably, the visual system uses such cues to construct 3-D representations from two-dimensional (2-D) retinal inputs. The current study examined 3-month-olds' sensitivity to the pictorial cues of line junction and shading—cues that adults use to derive 3-D structure and orientation information.

Over the past several decades, research has made considerable progress in delineating when infants become responsive to the spatial and structural information conveyed by various 3-D cues (for reviews, see Kavšek, 2003a; Kellman, 1995; Yonas, Arterberry, & Granrud, 1987). The general conclusion from this research has been that whereas infants derive 3-D information from motion-based cues early in life, the ability to derive 3-D information from pictorial cues does not emerge until later in life, that is, between 5 and 7 months of age (e.g., Arterberry, Bensen, & Yonas, 1991; Granrud & Yonas, 1984; Granrud, Yonas, & Opland, 1985; Kavšek, 2004; Kellman & Short, 1987; Yonas, Elieff, & Arterberry, 2002; Yonas, Granrud, Arterberry, & Hanson, 1986).

Lately, infants' sensitivity to the pictorial depth cue of line junctions has received increased research attention (e.g., Bhatt & Bertin, 2001; Kavšek, 1999, 2001; Yonas & Arterberry, 1994). This interest stems from research in computational science and computer vision (e.g., Barrow & Tenenbaum, 1981; Winston, 1992) indicating that line junction cues in images of scenes containing polyhedral objects can be used to derive object structure and spatial layout. According to this research, the most significant line junctions in 2-D renderings of polyhedral objects are Y, arrow, and T junctions. A combination of Y and arrow line junctions generates the impression of a cubic form in which the Y and arrow junctions correspond to corners formed by three and two visible sides, respectively (Fig. 1). T junctions (as found at the intersection of overlapping surfaces) mark boundary edges formed by occlusion and, hence, signify the relative depth of objects. A number of behavioral studies have validated these models by indicating that adult humans use line junctions contained in static images to derive 3-D shape and orientation information (Attwood, Harris, & Sullivan, 2001; Enns & Rensink, 1990, 1991; see also Enns, 1992; Sun & Perona, 1996a, 1996b, 1997).

Sensitivity to pictorial line junction cues has also been revealed in infants (Bhatt & Bertin, 2001; Kavšek, 1999, 2001; Yonas & Arterberry, 1994). Yonas and Arterberry (1994), for example, found that 7.5-month-olds distinguish between lines specifying corners and edges of depicted objects and those specifying surface markings on these objects. Similarly, Kavšek (1999) found that 8-month-olds distinguish between

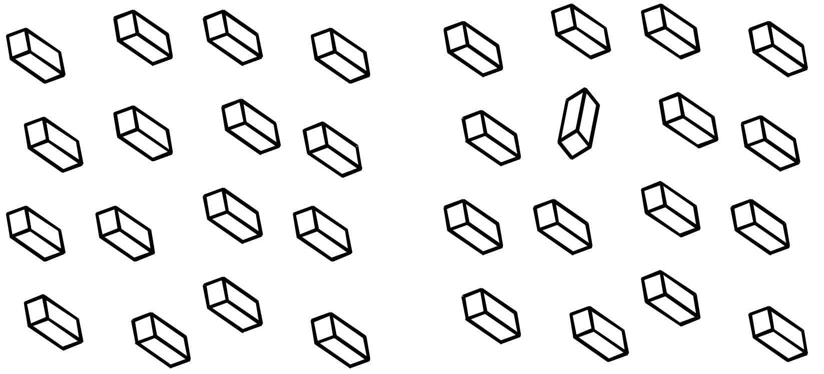

Fig. 1. Examples of habituation and test stimuli used by Bhatt and Bertin (2001, Experiment 1, 3-D condition).

curved line junctions representing the edges of depicted cylinders and those indicating surface markings of the same cylinders. Moreover, Kavšek (2001) demonstrated that 9-month-olds, but not 7-month-olds, perceive 3-D structure from successive static views of drawings of 3-D objects (i.e., elongated cubes and cylinders form specified by straight and curved trilinear line junctions) presented in various spatial orientations. Together, these findings led to the conclusion that sensitivity to line junction cues in static images emerges after approximately 7 months of age.

However, other research indicates sensitivity to line junction cues earlier in development than previously observed. For example, Bhatt and Bertin (2001) investigated 3-month-olds' processing of those trilinear line junctions that adults use to derive 3-D structure and orientation information (e.g., Enns, 1992; Enns & Rensink, 1990, 1991). Their study revealed that infants discriminated changes in orientation of line drawings containing a combination of Y and arrow junctions that, to adults, appear to have 3-D form (Fig. 1) but that infants failed to discriminate orientation changes in line drawings lacking 3-D interpretation (see also Bhatt & Waters, 1998). Moreover, employing a paradigm that examines infants' attentional engagement akin to the pop-out phenomena in adults (Quinn & Bhatt, 1998), Bhatt and Bertin (2001) found that rotation discrepancies in displays depicting line drawings of 3-D objects attracted and held infants' attention, whereas comparable displays with line drawings lacking 3-D interpretation did not. This suggests that even younger infants than previously believed (e.g., Kavšek, 1999; Yonas & Arterberry, 1994) are sensitive to line junction cues that signal 3-D structure and spatial layout and that, akin to pop-out in adults, discrepancies in 3-D cues selectively engage infants' attention.

Other researchers have also demonstrated early sensitivity to pictorial depth cues. For example, Kavšek (2003b) familiarized 4-month-olds with computer animations of circular displays with texture elements that were arranged to evoke the impression of either a sphere or a flat disc. Subsequently, he tested infants' ability to discriminate the spherical and flat displays. Results revealed that 4-month-old females, but not males, were able to differentiate between the two test displays, thereby indicating their sensitivity to directional alignment of texture elements. Moreover, Lécuyer, Durand,

and their colleagues (Durand & Lécuyer, 2002; Durand, Lécuyer, & Frichtel, 2003; Lécuyer & Durand, 1998) found that when 2-D representations of 3-D scenes are enriched by employing dynamic displays or by providing additional 3-D information, 3- to 4-month-olds are able to solve complex cognitive problems presumably by responding to 3-D cues such as interposition and linear perspective. These studies suggest that, under certain experimental conditions, infants under 5 months of age are capable of responding to pictorial 3-D cues. These findings are consistent with the results obtained by Bhatt and Bertin (2001) and Bhatt and Waters (1998).

It must be noted that infants' sensitivity to the pictorial depth cues investigated in the aforementioned studies might not necessarily translate into infants' ability to extract complete 3-D form or spatial meaning. What these studies show is that, under certain circumstances (e.g., embedding the pictorial depth cue in a textural or pop-out display, providing additional 3-D cues), young infants are sensitive to pictorial depth cues. Moreover, when an early sensitivity to line junction cues is observed, it is to those line junctions that the mature visual system uses to perceive 3-D layout and structure. This early sensitivity might be a predecessor to infants' later functional responses to pictorial depth cues (e.g., reaching to the apparently nearer object).

The goal of the current work was to replicate Bhatt and Bertin's (2001) finding of early sensitivity to the pictorial depth cue of line junctions. In addition, we aimed to extend those results by investigating infants' sensitivity to pictorially signaled orientation changes in the 3-D depth plane. As noted previously, Bhatt and Bertin demonstrated that 3-month-olds are sensitive to line junctions that adults use to derive 3-D structure and spatial layout from static images of polyhedral objects. That is, infants discriminated orientation changes in line drawings that, specified by the holistic arrangement of line junction cues, had a 3-D interpretation of elongated cubes. The orientation changes of the line drawings in that study, however, involved all three axes of the Cartesian coordinate system. That is, in addition to an apparent 3-D depth change (z axis), the discrepant line drawing also differed from the surrounding line drawings in its 2-D orientation (x and y axes). Thus, it is not clear whether 3-month-olds are sensitive to line junction cues that signal orientation changes solely in the 3-D depth plane. We examined this issue in the current experiments by changing the target line drawing's orientation only about the z axis.

A second issue examined in the current study concerned the question of whether adding shading information to the line drawings of elongated cubes influences infants' perception of pictorially signaled orientation changes in the 3-D depth plane. Research has revealed that humans readily use shading information to extract depth and spatial layout information from 2-D stimuli (e.g., Braun, 1993; Mamassian, Jentzsch, Bacon, & Schweinberger, 2003; Ramachandran, 1988). Specifically, superimposing shading on line drawings of cubes (and thereby enhancing the information conveyed by the line junction about the object's shape and orientation) facilitated adults' searches for orientation changes relative to their searches for analogous orientation changes in cubes without shading (Attwood et al., 2001; Enns & Rensink, 1990; Humphrey, Symons, Herbert, & Goodale, 1996; Sun & Perona, 1996b). Infants are also sensitive to shading cues. For example, research with both human and chimpanzee infants (5–7 and 4–10 months of age, respectively) have revealed that they reach reliably more for an apparent convex stimulus than for an apparent concave stimulus specified by shading gradients (e.g., Granrud et al., 1985; Imura & Tomonaga, 2003; see also Bhatt & Waters, 1998). This indicates that infants, like adults, derive 3-D shape and spatial layout from shading information. The current study examined whether shading cues influence 3-month-olds' perception of line junction cues that, to adults, signal orientation changes in the 3-D depth plane.

Experiment 1

Bhatt and Bertin (2001) found that 3-month-olds are sensitive to combinations of pictorial line junctions that signal 3-D structure and orientation to adults and also that orientation discrepancies in 2-D stimuli that appear to have 3-D structure, but not those that lack 3-D structure, engage infants' attention. These results were consistent with prior research suggesting that adults recover 3-D structure and orientation from information contained in line drawings and that orientation changes in depictions of 3-D objects are detected much faster than comparable depictions without 3-D interpretation (Enns, 1992; Enns & Rensink, 1990, 1991). However, with adults, the orientation changes of the target line drawing were in the 3-D depth plane only (Fig. 2). That is, the stimulus manipulation in the adult studies left the drawing's outline unaltered and changed only the drawing's central lines, which determined its new orientation in the 3-D depth plane (Attwood et al., 2001; Enns, 1992; Enns & Rensink, 1990, 1991; Sun & Perona, 1996a, 1996b, 1997). For infants, in contrast, the rotation changes of the target line drawing consisted of rotations about the x and y axes in addition to an apparent change in the 3-D depth orientation of the line drawing (Bhatt & Bertin, 2001; cf. Figs. 1 and 2). That is, in addition to an apparent change of the target line drawing in 3-D depth (e.g., an upward-pointing elongated cube in a field of downward-pointing cubes), the orientation of the outline contour of

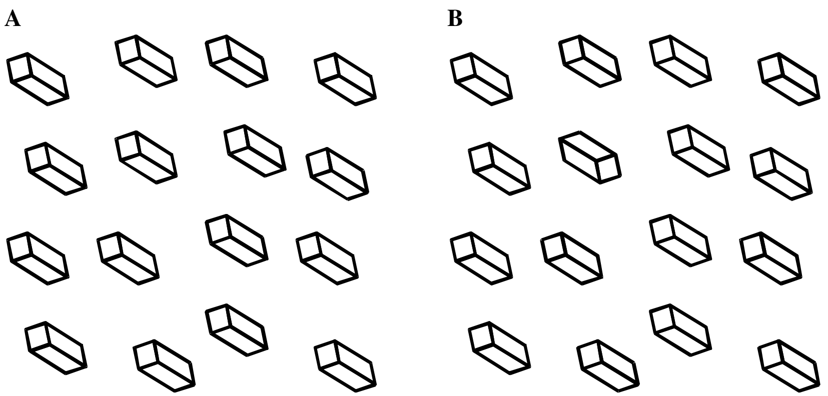

Fig. 2. Examples of the test stimuli used in Experiment 1 (3-D with no shading). Infants were habituated to two homogeneous arrays of the kind displayed in panel A before being tested with panel A paired with panel B.

the target line drawing also differed in the 2-D picture plane [the target cube was tilted 100° to the rest of the elongated cubes (Fig. 1)]. Thus, infants in the 3-D condition of the Bhatt and Bertin (2001) study could base their discrimination on the combination of changes in all three axes. Consequently, it is not clear whether 3-month-olds are sensitive to orientation changes in depicted 3-D objects that are signaled solely by cues in the 3-D depth plane. To investigate this issue, we employed the types of stimuli that Enns and his colleagues (Enns, 1992; Enns & Rensink, 1990, 1991) used with adults. That is, the orientation change of the target line drawing was only in the 3-D depth plane as specified by the rotation change of the internal Y junction (Fig. 2).

Method

Participants

A total of 28 full-term 3-month-olds (11 girls and 17 boys, mean age = 97.54 days, $SD = 7.88$) participated in this experiment. They were recruited from a database consisting of names of infants whose caregivers had volunteered to participate in studies of child development. Infants were predominantly Caucasians from middle-class backgrounds. An additional 12 infants started the experiment but were excluded from the final sample due to crying ($n = 7$), falling asleep ($n = 2$), or failing to sample both test patterns during the test trials ($n = 3$).

Stimuli

The stimuli used were similar to the line drawings of 3-D stimuli used by Bhatt and Bertin (2001; see Fig. 1) except that the orientation difference between the single discrepant and the surrounding line drawings was in the 3-D depth plane only. That is, the orientation change was about the *z* axis, leaving the outline of the rotated line drawing unaltered and changing only the placement of the internal lines (Fig. 2). In general, the stimuli used in this and the following experiment were the same as those used by Enns and Rensink (1990) with adults. The line drawings consisted of black lines 0.2 cm wide (visual angle 0.29°) arranged to form the impression of elongated solid cubes set against a white background. Because computer displays are typically not spatially uniform in luminance, the luminance of the stimulus elements was measured at five randomly chosen locations on the display. The average luminance of the white background was 195.2 lux, whereas the average luminance of the black lines was 1.7 lux. From the infants' viewpoint, each line drawing subtended roughly 2.86° and each of the arrays subtended 17.06° × 17.06°. During familiarization, two identical homogeneous arrays, each of 16 line drawings, were presented (Fig. 2A). During testing, a familiar homogeneous array was paired with a test array that contained a single misoriented line drawing amid familiar line drawings (Fig. 2B). Two different versions of the familiarization and test stimuli were used. Specifically, the line drawings in the familiarization arrays were oriented at either 80° or 260°. The discrepant line drawing was rotated 180° with respect to the familiar line drawings, leading to an orientation change of the internal Y junction without altering the line drawing's outline. The position of the discrepant line drawing in the test array was varied across infants, such that it was located at the top left or bottom right of the test array, diagonally one position away from the center of the array.

Apparatus and procedure

The apparatus and procedure used were the same as those used in prior studies (e.g., Bertin & Bhatt, 2001; Bhatt & Bertin, 2001). The stimuli were presented on a 20-inch monitor located at the front wall of a darkened chamber, approximately 40 cm in front of the infants, who were seated in an infant car seat. The infants' gaze direction and duration were recorded with a video camera located on top of the computer monitor. A television monitor and videocassette recorder (VCR), connected to the video camera, allowed the experimenter to monitor and record the infants' gaze. The television monitor, VCR, and computer used to display the stimuli were located outside of the testing chamber. During the test session, the only source of light was the computer monitor.

As in Bhatt and Bertin (2001), an infant-control habituation procedure was used in this and the following experiment (Horowitz, Paden, Bhana, & Self, 1972). On each habituation trial, infants were exposed to two identical homogeneous patterns that remained on-screen until the infants looked away for 2 s or until 60 s had elapsed. Habituation trials were repeated until the mean look duration during three consecutive trials for each infant was less than or equal to half of the mean look duration during the first three trials for the same infant or until the infant had gone through a maximum of 20 habituation trials. Three infants went through all 20 familiarization trials without meeting the habituation criteria. Their data are included in the final analysis. The mean number of habituation trials was 10.29 ($SD = 4.39$).

Immediately after the last habituation trial, infants were exposed to two 10-s test trials during which a familiar pattern was paired with another that contained a single misoriented line drawing amid familiar line drawings (Fig. 2). The left–right positioning of the pattern with the discrepant line drawing in the first test trial was counterbalanced across participants. This pattern's position was reversed on the second test trial. Data coding of the test trial performance was conducted offline by an experimenter who was unaware of the left–right location of the test pattern. The performances of eight randomly chosen participants were coded by another naive experimenter to examine interobserver reliability. The average Pearson correlation between the two observers was .99.

Results and discussion

Table 1 displays the mean looking times during the first and last three habituation trials as well as the mean preference scores exhibited during the test. As required by the procedure, infants' looking times declined significantly from the first to the last three habituation trials. The mean preference score is the percentage of total looking toward the test stimulus that was devoted to the pattern with the single misoriented line drawing. A mean score of 50% indicates no preference, whereas a score greater

Table 1
Means and standard errors of fixation duration during habituation and test trials and percentages novelty preference during test trials in Experiment 1 (3-D with no shading)

First three habituation trials (s)	Last three habituation trials (s)	Test trials (s)	
41.58 (3.51)	17.89 (2.38)	16.15 (0.60)	
Preference for novel pattern during test trials			
M (*SE*)	*N*	*t* (vs. chance)	*p* (two-tailed)
49.38 (2.80)	28	−.22	>.05

Note. Standard errors are in parentheses.

than 50% indicates a preference for the pattern with the single misoriented line drawing. As can be seen in Table 1, the novelty preference score was not significantly different from the 50% chance level, $t(27) = -.22$, $p > .05$. To better understand the nature of the data, we explored the distribution of the preference scores in more detail. When novelty preference was defined as scores $\geqslant 55\%$ (e.g., Rose, Feldman, & Jankowski, 2001) and familiarity preference was defined as scores $\leqslant 45\%$, 12 infants exhibited a familiarity preference, 10 infants exhibited a novelty preference, and 6 infants exhibited a null preference (scores 46–54%). A chi-square test revealed no differences in the frequencies of infants who displayed novelty, familiarity, and null preference, $\chi^2(2, N = 28) = 2.00$, $p > .10$.

The results indicate that, in contrast to Bhatt and Bertin (2001, Experiment 1, 3-D condition), 3-month-olds in the current experiment failed to detect the discrepancy in the array that contained a single misoriented 3-D line drawing. Infants in the Bhatt and Bertin study may have used both the apparent 3-D orientation change between the line drawings (an upward-pointing elongated cube in a field of downward-pointing cubes) *and* the disparity between the orientation of the target line drawing and surrounding line drawings in the 2-D picture plane (the discrepant elongated cube was tilted 100° to the rest of the cubes) to discriminate the misoriented line drawing. For infants in the current experiment, the orientation change in the test arrays consisted only of a rotation about the 3-D depth plane. It is possible that line junction cues signaling such orientation changes (i.e., directional change of central Y junction while line drawings' outer contour remained unaltered) are, by themselves, not sufficient for 3-month-olds to detect rotation changes about the *z* axis. In Experiment 2, we investigated whether the addition of surface shading to the line drawings facilitates infants' ability to discriminate orientation changes in the 3-D depth plane.

Experiment 2

Adults effectively use shading information in pictures to derive the 3-D structure and orientation of objects (e.g., Braun, 1993; Ramachandran, 1988; Sun & Perona, 1996a, 1996b, 1997, 1998; Symons, Cuddy, & Humphrey, 2000). Shading information also influences the speed at which adult observers perceive scenes containing polyhedral objects. For example, visual search experiments reveal that the slopes of search functions are reduced when observers look for rotation discrepancies in shaded cubes relative to analogous discrepancies in cubes without shading (Attwood et al., 2001; Enns & Rensink, 1990; Humphrey et al., 1996). Thus, it seems that the addition of shading to line junction cues facilitates the perception of 3-D orientation discrepancies in adults. In Experiment 2, we tested whether a similar facilitation is seen at 3 months of age.

The ability to perceive depth from shading has also been observed in human infants. Granrud and colleagues (1985) found that when 7-month-olds monocularly viewed a photograph in which shading gradients specified apparent convexity and concavity, the infants reached preferably for the apparent convexity. Control conditions (binocular viewing that provided information about the actual flatness of the scene) ruled out alternative explanations and reinforced the conclusion that infants' reaching behavior was based on perceived depth from shading. Using the same basic procedure, Imura and Tomonaga (2003) found that 4- to 10-month-old chimpanzees similarly displayed significantly more reaches and looks toward a 2-D image containing shading cues that signaled convexity relative to those that signaled concavity, suggesting that the sensitivity of pictorial cues such as shading might have been acquired during the course of primate evolution (see also Tomonaga, 1998).

Visual preference procedures have revealed sensitivity to shading information in even younger infants. Bhatt and Waters (1998) found that 3-month-olds, who were familiarized with patterns of images that appeared to be 3-D cubes illuminated from the top, subsequently preferred a test pattern that contained a single cube that appeared to be illuminated from the bottom. Similarly, 4-month-olds who were familiarized to 2-D arrays of top-shaded circles (apparent convexities) discriminated a 2-D array containing embedded circles that were illuminated from the bottom (apparent concavities) (Imura, Tomonaga, Yamaguchi, & Yagi, 2004). Thus, across different procedures, stimuli, and species, these results suggest that sensitivity to shading information that underlies adults' perception of 3-D images in pictures develops early in life. Against this background, it is conceivable that adding shading information to the type of line drawings used in Experiment 1 would assist 3-month-olds in their discrimination of orientation changes in the 3-D depth plane. This was the issue addressed in Experiment 2.

We compared the performance of one group of infants who were tested with shaded line drawings that, to adults, appeared to have 3-D structure (Fig. 3, 3-D) with the performance of a control group of infants who were tested with similar drawings that did not have 3-D structure (Fig. 3, 2-D). Like adults, 3-month-olds are sensitive to changes in orientation of line drawings that appear to have 3-D structure but are not sensitive to comparable changes in line drawings that do not have a ready 3-D structure interpretation (Bhatt, 1999; Bhatt & Bertin, 2001; Bhatt & Waters, 1998; Enns & Rensink, 1990, 1991; Sun & Perona, 1996b). Consequently, if infants base their discrimination of the pictorially signaled orientation change in the 3-D depth plane on the apparent three-dimensionality of the elongated cubes (signaled by the particular line junctions), they should exhibit sensitivity only to images that appear to have 3-D structure (Fig. 3, 3-D) and not to images that have only 2-D structure (Fig. 3, 2-D). Although such results would not warrant the conclusion that

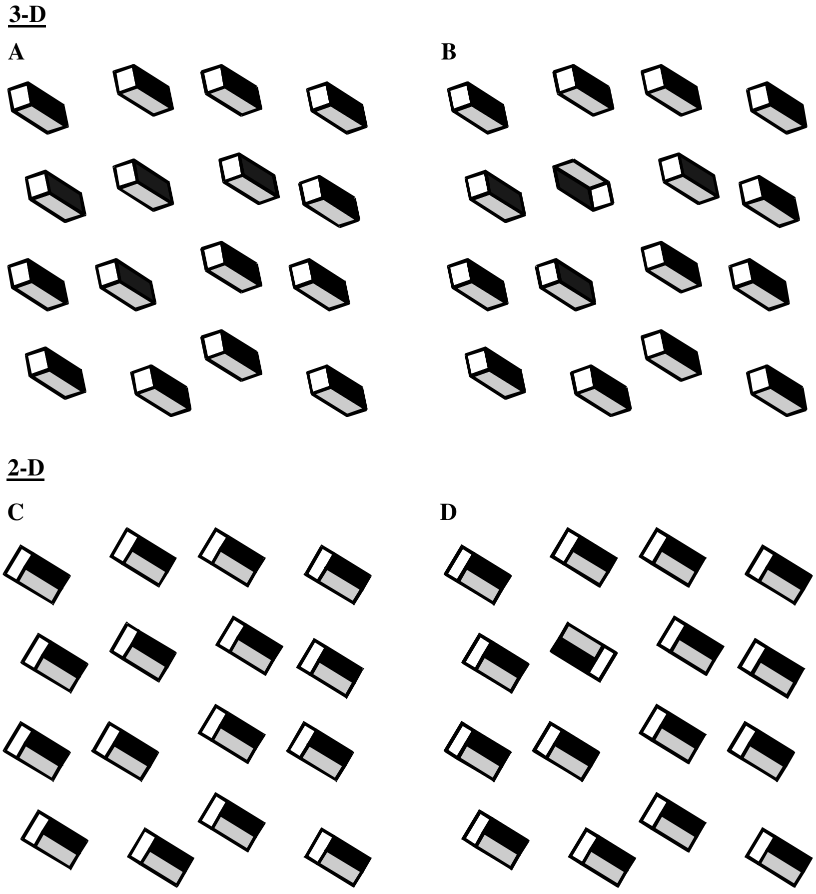

Fig. 3. Examples of the test stimuli used in Experiment 2 (3-D and 2-D with shading). Infants were habituated to two homogeneous arrays of the kind displayed in panels (A) (3-D group) and (C) (2-D group) before being tested with panel (A) paired with panel (B) (3-D group) and panel (C) paired with panel (D) (2-D group).

infants perceive the complete 3-D property of the elongated cubes in the same manner as do adults and older children, they would demonstrate that infants, as early as 3 months of age, are responsive to those pictorial cues that adults use to derive 3-D form and spatial layout of objects depicted in the picture plane.

Method

Participants

A total of 56 full-term 3-month-olds (24 girls and 32 boys, mean age = 98.70 days, $SD = 7.86$) participated in this experiment (28 infants each in the 3-D and 2-D groups). These infants were recruited in the same manner as those in Experiment 1. An additional 27 infants (3-D: $n = 17$; 2-D: $n = 10$) started the experiment but were excluded from the final sample due to crying ($n = 22$), falling asleep ($n = 2$), or failing to sample both test patterns during the test trials ($n = 3$).

Stimuli

The 3-D stimuli used in this experiment were the same as those used in Experiment 1 except that shading was superimposed on the line drawings. In line with the stimuli used by Enns and Rensink (1990, 1991), shading was in the form of solid black (100% black), gray (40% black), and white (0% black) fillings applied to the sides of the trihedral line drawing (Fig. 3). The 2-D stimuli were generated in such a way as to match the 3-D stimuli in terms of shading and size, but they featured T and L junctions instead of Y and arrow junctions and, consequently, imparted a flat appearance to the polygons (Fig. 3). This type of shaded 2-D stimuli was also used by Enns and Rensink (1990) with adult participants. The total surface areas of the 3-D and 2-D shaded line drawings were the same as were the proportions and spatial relations of the shaded faces of the polygons (Fig. 3). The white background was the same as that used in Experiment 1. Similarly, the black shaded regions and the black lines that made up the stimulus elements in this experiment were the same as the black color used in Experiment 1. The average luminance of the gray region, measured in the same way as the stimuli in Experiment 1, was 127.8 lux. In all other respects, the stimuli of Experiment 2 were analogous to those of Experiment 1.

Apparatus and procedure

The apparatus and procedure used were identical to those used in Experiment 1. That is, after infants individually reached their habituation criteria, they were exposed to two 10-s test trials in which the familiar pattern (Figs. 3A and C) was paired with another that contained a single misoriented line drawing (Figs. 3B and D). Two infants (one in each of the 3-D and 2-D groups) went through all 20 familiarization trials without meeting the habituation criteria. Their data are included in the final analysis. The mean numbers of habituation trials were 8.96 ($SD = 3.84$) for the 3-D group and 8.46 ($SD = 3.90$) for the 2-D group.

As in Experiment 1, data coding of the test trial performance was conducted offline by an experimenter who was unaware of the left–right location of the test pattern. The performances of 16 randomly chosen participants were coded by another naive experimenter to examine interobserver reliability. The average Pearson correlation between the two observers was .99.

Results and discussion

Table 2 displays the mean looking times during the first and last three habituation trials. A Group (3-D vs. 2-D) × Trial (first three vs. last three) analysis of variance (ANOVA) was conducted to test whether the two types of stimuli were treated differently during the habituation phase. The analyses revealed a trial main effect, $F(1, 54) = 282.28$, $p < .001$. No other main or interaction effect was significant. Thus,

Table 2
Means and standard errors of fixation duration during habituation and test trials and percentages novelty preference during test trials in Experiment 2 (3-D and 2-D with shading)

Group	First three habituation trials (s)	Last three habituation trials (s)	Test trials (s)	
3-D	39.04 (3.05)	13.22 (1.52)	12.18 (0.65)	
2-D	38.34 (2.59)	13.53 (1.60)	11.98 (0.82)	
Preference for novel pattern during test trials				
Group	M(*SE*)	*N*	*t* (vs. chance)	*p* (two-tailed)
3-D	56.62 (2.71)	28	2.44	<.03
2-D	48.86 (2.44)	28	−.47	>.05

Note. Standard errors are in parentheses.

although infants exhibited a significant decline in looking time from the first three to the last three habituation trials (as required by the procedure), there was no evidence to suggest that the 3-D stimuli were treated differently from the 2-D stimuli during the habituation phase of the experiment.

Table 2 also displays the novelty preference scores exhibited by the two groups during the test. The mean preference score is the percentage of total looking toward the test stimulus that was devoted to the pattern with the single misoriented shaded line drawing. Infants in the 3-D group looked more toward the pattern with the single novel line drawing, whereas infants in the 2-D group did not exhibit a preference. Specifically, preference for the pattern with the single misoriented shaded line drawing was significantly greater than the chance level of 50% in the 3-D condition, $t(27) = 2.44$, $p < .03$, whereas this preference was not significantly different from the chance level in the 2-D condition, $t(27) = -.47$, $p > .05$. Moreover, there was a significant difference between the preference scores of the two groups, $t(54) = 2.13$, $p < .05$. Total looking duration toward the test display did not differ between the 3-D and 2-D groups, $p > .10$ (Table 2).

Analogous to Experiment 1, we explored the distribution of the preference scores in the 3-D and 2-D conditions. This examination revealed that only 5 infants in the 3-D group exhibited a familiarity preference (scores $\leqslant$45%), whereas 18 infants exhibited a novelty preference (scores $\geqslant$55%). A chi-square test indicated that the number of infants who displayed a novelty preference was significantly greater than the number of infants who displayed a familiarity preference or a null preference (scores 46–54%), $\chi^2(2, N = 28) = 12.07$, $p < .01$. In contrast to the 3-D group, most infants in the 2-D group exhibited a null preference ($n = 14$). Only 8 and 6 infants displayed familiarity and novelty preferences, respectively. A chi-square test revealed no differences in the frequency of infants who displayed novelty, familiarity, and null preferences, $p > .10$. These results buttress the conclusion that 3-month-olds are able to discriminate displays containing pictorially specified orientation changes in the 3-D depth plane provided that the line drawings have a 3-D interpretation and shading information is available.

The results from Experiments 1 and 2 suggest that shading matters when infants process pictorial cues. Specifically, 3-month-olds discriminated pictorially defined rotation changes about the depth axis of shaded elongated cubes (Experiment 2, 3-D group) but were not able to detect comparable changes of simple line drawings of elongated cubes devoid of shading information (Experiment 1). Thus, as with adults (Attwood et al., 2001; Enns & Rensink, 1990; Humphrey et al., 1996; Sun & Perona, 1996b), shading information facilitates infants' ability to discriminate displays in which pictorial cues (Y and arrow junctions, shading) specify discrepancies in the 3-D depth plane. However, in this study, shading was necessary for infants to exhibit such discrimination, whereas for adults shading cues merely improve discrimination performance.

The results also indicate that infants' discrimination was not simply due to the detection of changes in luminance patterns provided by the 180° rotation of the target item. Both the 3-D and 2-D stimuli provided shading information of the same kind, but only when the images depicted apparent 3-D objects were infants able to discriminate orientation changes. These results demonstrate that infants are sensitive to orientation discrepancies in displays that, to adults, appear to contain 3-D shapes.

General discussion

The current study examined 3-month-olds' sensitivity to pictorially signaled orientation changes in the 3-D depth plane. The results revealed that 3-month-olds, like adults, are able to detect orientation discrepancies in the depth plane when tested with shaded line drawings that have a 3-D interpretation but not when tested with images that do not have a 3-D interpretation. However, 3-month-olds, unlike adults, failed to detect such orientation changes when tested with line drawings without shading information. These findings indicate that infants as young as 3 months of age are sensitive to some of the same pictorial cues that adults use to process 3-D structure and orientation. However, sensitivity to displays consistent with orientation changes in the 3-D depth plane signaled only by trilinear line junctions does not appear to be available at 3 months of age.

Previously, Bhatt and Bertin (2001) found that 3-month-olds discriminated orientation discrepancies in static images depicting 3-D objects and that discrepancies in 3-D cues attracted and held infants' attention. As described earlier, the individual discrepantly oriented line drawings in that study were defined by apparent 3-D depth as well as by 2-D picture plane changes (i.e., changes in x,y, and z axes). Hence, infants could have based their discrimination on a combination of apparent 3-D depth and 2-D differences. In contrast, the target line drawing's novel position in the current experiments was defined only by an orientation change in the 3-D depth plane (signaled by the position change of the drawing's trilinear line junction). Thus, infants could base their discrimination only on the directional change of the central trilinear line junction that, by rotating the elongated cube 180°, signaled the apparent orientation change in the 3-D depth plane. Faced with this task, 3-month-olds were able to discriminate displays with a single misoriented elongated cube in the presence of shading information (Experiment 2) but not in its absence (Experiment 1).

Although the current findings point to an early sensitivity to some of the same pictorial cues that adults use to infer 3-D information from static images, the findings seem to contradict prior research suggesting that it is not until approximately after 7 months of age that infants begin to be able to respond to a variety of pictorial depth cues (for reviews, see Kavšek, 2003a; Kellman, 1995; Yonas et al., 1987). However, although many studies that make this claim (e.g., Granrud & Yonas, 1984; Granrud et al., 1985; Yonas et al., 1986) investigated infants' ability to use pictorial cues as sources of information to compute a particular 3-D shape or spatial layout (e.g., apparent convexity, nearness of a surface/object), the current study made no attempt to examine the exact precision of infants' 3-D shape or depth perception. Rather, the emphasis was on infants' sensitivity to discrepancies in pictorial cues that adults use to derive changes in spatial layout of pictorially presented 3-D scenes. Young infants might be sensitive to 3-D cues in static images, but they might not have developed the capacity to use these cues to derive actual 3-D structural and spatial meaning. Early perceptual sensitivity to pictorial depth cues may function as a precursor to higher level skills of extracting 3-D structure and spatial meaning from such cues. Clearly, more studies are required to determine how early sensitivity to pictorial cues relates to later function in 3-D space.

It should also be noted, however, that some studies investigating infants' sensitivity to line junction cues suggest that only at approximately 7 to 8 months of age do infants begin to attend selectively to line information that specifies object structure (Kavšek, 1999; Yonas & Arterberry, 1994). The findings of the current study seem to conflict with this developmental timeline. We suggest that methodological aspects might account for the differences in findings. Most prior studies employed the habituation–dishabituation paradigm (e.g., Kavšek, 1999; Yonas & Arterberry, 1994) in which infants are habituated to a particular line drawing and subsequently tested with two alternately presented displays, both differing from the habituation display on a critical aspect. Such a procedure requires that infants form a memory trace of the habituation display and use it during the test to compare the test display with a mental representation of the habituation display. In contrast, the current study used a paired-comparison procedure in which the familiar pattern occurred simultaneously with the pattern that contained the newly oriented line drawing, thereby eliminating memory demands. Moreover, the current study used stimuli where the pictorial depth cue was embedded in a pop-out display that provided several contrasts between the target line drawing and the other line drawings. The paired-comparison procedure, the pop-out display, or a combination of both might have enabled 3-month-olds to detect the discrepant shaded 3-D, but not 2-D, line drawing.

As noted earlier, other studies have found that young infants are sensitive to information in pictorial displays that, to adults, create the impression of depth or 3-D structure (Bhatt & Bertin, 2001; Bhatt & Waters, 1998; Durand & Lécuyer, 2002; Durand et al., 2003; Imura et al., 2004; Kavšek, 2003b; Lécuyer & Durand, 1998). For example, Imura and colleagues (2004) used a paired-comparison procedure and pop-out stimuli and found that 4-month-olds were able to discriminate a vertical change in shading direction signaled by pictorial cues. Thus, there is convergent evidence from different laboratories indicating early sensitivity to pictorial depth cues.

The contrast between the results of Experiment 1 of the current study and those of Bhatt and Bertin (2001), both of which involved the use of line drawings without shading information, suggests that 3-month-olds are not sensitive to line junction cues that, to adults, indicate an apparent 3-D depth orientation change in the absence of 2-D picture plane changes in the tilt of line drawings. The contrast between the results of Experiment 1 and those of Experiment 2 (3-D group) of the current study, where the only difference between the line drawings was the addition of shading information, suggests that 3-month-olds are not sensitive to pictorially signaled orientation changes in the 3-D depth plane in the absence of shading information. Together, these results suggest that the visual system of 3-month-olds might take advantage of any information that is available. That is, infants in the Bhatt and Bertin (2001) study may have used discrepancies in all three axes to recognize orientation changes. Likewise, infants in Experiment 2 of the current study may have used the orientation cues from line junction and shading additively to discriminate the test displays that, to adults, signaled orientation changes in the 3-D depth plane.

It is also conceivable, however, that under complex situations (e.g., where only the direction of the central Y junction of the target line drawing is changed while the target's outer contour is left intact), it is necessary to give more perceptual indicators (e.g., shading information as in Experiment 2) for young infants to discriminate pictorial depth cues. Prior research reveals that after receiving additional visual information, infants' discrimination is facilitated and younger infants often respond at a developmentally older age level (e.g., Durand & Lécuyer, 2002; Durand et al., 2003; Johnson & Aslin, 1996). For example, Durand and Lécuyer (2002) added static linear perspective cues to a computerized version of the Baillargeon, Spelke, and Wasserman (1985) drawbridge experiment and found that under these circumstances, but not under circumstances devoid of 3-D information (Cashon & Cohen, 2000), the original Baillargeon and colleagues' (1985) results with 3-D stimuli were replicated. Thus, shading information in the current study might have functioned as supplementary information to line junction cues that made discrimination possible. Consequently, neither line junction nor shading cues may have functioned in isolation; instead, these cues may have functioned in conjunction with each other. Alternatively, of course, shading information by itself may have been sufficient to enable infants to detect changes in the pictorial depth plane.

The results of Experiment 2 of the current study indicate that infants' successful discrimination in the 3-D condition was not due solely to changes in luminance patterns (induced by the 180° rotation of the shaded target line drawing); rather, it also involved the perception of the apparent three-dimensionality of the polygons (signaled by Y and arrow line junctions). Indeed, infants did not discriminate comparable orientation changes when the polygons were flat 2-D images as specified by T and L junctions. Because the only differences between the images in the 3-D and 2-D conditions were the type of line junctions (and the resulting 3-D vs. 2-D nature of the line drawings), it seems reasonable to infer that infants' recognition of orientation changes in the 3-D condition must have been due to the perception of the particular line junction cues that bestowed the shaded line drawings with their apparent 3-D nature. Previous research with infants and adults has revealed similar findings (e.g., Bhatt, 1999; Bhatt & Bertin, 2001; Bhatt & Waters, 1998; Enns & Rensink, 1990, 1991; Sun & Perona, 1996b). Thus, 3-month-olds appear to be sensitive to the same cues that adults use to derive 3-D structure and orientation from 2-D images depicting polyhedral objects. A visual system that is sensitized to process pictorial cues pertaining to three-dimensionality seems ecologically advantageous given that retinal input is invariably two-dimensional. Whether this sensitivity generalizes to actual 3-D objects, and how exactly and to what extent junction cues are used by young infants to compute 3-D information from 2-D displays, remains to be investigated.

It could be argued that infants' discrimination in the 3-D condition of Experiment 2 was due to a low-level computation bias for Y and arrow junctions (which in the natural visual environment signal corners and edges of actual objects) over T and L junctions. However, Bhatt and Bertin (2001, Experiment 1), found that 3-month-olds were not sensitive to discrepancies in line drawings that contained all necessary trilinear junctions to form 3-D images but had no connecting lines to form depictions of coherent 3-D objects. In other words, the presence of Y and arrow junctions alone was not enough for infants to exhibit behavior consistent with 3-D cue sensitivity. Thus, it is unlikely that infants' sensitivity to the pictorial depth cues in the 3-D condition of Experiment 2 in the current study was solely a response to the presence of Y and arrow junction cues.

In summary, the current study revealed that 3-month-olds are sensitive to pictorial cues that, to adults, signal depth plane orientation changes in images provided that shading information is available. Moreover, the ability to recognize such orientation changes is specific to images that have a 3-D interpretation. Together, these results suggest that infants as young as 3 months of age are sensitive to some of the same pictorial cues that adults use to derive 3-D orientation in the depth plane.

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Infants' perception of information along object boundaries: Concavities versus convexities

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Abstract

Object parts are signaled by concave discontinuities in shape contours. In seven experiments, we examined whether 5- and $6\frac{1}{2}$-month-olds are sensitive to concavities as special aspects of contours. Infants of both ages detected discrepant concave elements amid convex distractors but failed to discriminate convex elements among concave distractors. This discrimination asymmetry is analogous to the finding that concave targets among convex distractors pop out for adults, whereas convex targets among concave distractors do not. Thus, during infancy, as during adulthood, concavities appear to be salient regions of shape contours. The current study also found that infants' detection of concavity is impaired if the contours that define concavity and convexity are not part of closed shapes. Thus, for infants, as for adults, concavities and convexities are defined more readily in the contours of closed shapes. Taken together, the results suggest that some basic aspects of part perception from shape contours are available by at least 5 months of age.

Keywords: Infancy; Object perception; Part perception; Concavity discrimination; Boundary perception

Introduction

It is often assumed that object representations are composed of parts (e.g., Biederman, 1987; Feldman & Singh, 2005; Hoffman & Richards, 1984; Marr & Nishihara, 1978;

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Palmer, 1977; Singh & Hoffman, 2001; Singh, Seyranian, & Hoffman, 1999). For instance, Biederman's (1987) recognition-by-components model assumes that all shape representations are derived from the combination of a limited number of geons. Similarly Marr and Nishihara (1978) proposed that a critical stage in the recognition of shapes is the computation of basic volumetric parts.

Given the importance of parts to shape perception, the question arises as to how the human visual system processes parts. Although not all theorists agree on the specifics of how parts are derived or on the exact nature of parts [cf. Biederman's (1987) assumption of a limited number of parts with Singh et al.'s (1999) notion of general parts], there is wide-ranging agreement that points of curvature changes along the edges of objects are significant for part decomposition (e.g., Attneave, 1954; Biederman, 1987; Feldman & Singh, 2005; Hoffman & Richards, 1984; Marr & Nishihara, 1978; Singh et al., 1999).

Hoffman and Richards (1984) noted the special significance of negative minima of curvature (concavities) for parts. They proposed the minima rule for part perception, which posits that shapes are segmented using negative minima of curvature as part boundaries. In other words, parts are signaled by concavities; where a part connects with the rest of an object, there is a concave discontinuity in the contour.

There is considerable empirical support for the minima rule (Singh & Hoffman, 2001; Xu & Singh, 2002). Moreover, the importance of this rule for general visual processing is indicated by the fact that diverse phenomena such as short-term memory for shapes (Braunstein, Hoffman, & Saidpour, 1989), the perception of symmetry and repetition (Baylis & Driver, 1994), and the assignment of figure and ground (Hoffman & Singh, 1997) have been demonstrated to be affected by this rule.

One significant piece of support for the minima rule comes from asymmetries in the detection of concavities versus convexities. Adults' search for a concave target among convex distractors is fast and efficient, whereas their search for a convex target among concave distractors is slow and serial (Hulleman, te Winkle, & Boselie, 2000; Wolfe & Bennett, 1997; Xu & Singh, 2002). Such asymmetries have been used as an index of the preattentive processing of features. That is, if an element with a particular feature is detected rapidly among distractors that do not contain that feature but the reverse is not true, then it is assumed that the feature is processed preattentively (Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 1994, 2000). Thus, the concavity–convexity asymmetry (and other visual search phenomena predicted by the minima rule) has led to the conclusion that the adult visual system "segments shapes into parts, using negative minima of curvature, and ... it does so rapidly in early stages of visual processing" (Xu & Singh, 2002, p. 1039).

The current research examined infants' sensitivity to the negative minima of curvature. A considerable amount of prior research has addressed the issues of how infants segregate objects from each other and, conversely, how they perceive object unity in the contexts of occlusion and illusory contours (for reviews, see Arterberry, 2001; Condry, Smith, & Spelke, 2001; Johnson, 2000; Kellman & Arterberry, 1998; Needham & Ormsbee, 2003). Some research has addressed the issue of how infants attend to information in edges. Salapatek (1968, 1975) found that fixations of young infants tend to focus on vertices of shapes. Yonas and Arterberry (1994) demonstrated that 7-month-olds are more likely to notice changes in edges of objects than in surface markings. Bhatt and Bertin (2001) found that 3-month-olds attend to line junctions in edges that signal three-dimensional (3-D) structure and orientation information to adults. Frick and Colombo (1996) determined that deletion of vertices interferes with the processing of shape information during infancy. Taken together, these studies indicate that edges are important for object perception during infancy. However, to our knowledge, no study has examined infants' sensitivity to concavities and convexities in edges. This was the issue addressed in the current study.

We examined 5- and $6\frac{1}{2}$-month-olds' processing of concavities and convexities in object contours. In Experiments 1, 2, 4, 5, and 6, we examined whether infants exhibit an asymmetry in the detection of concave versus convex targets in visual arrays. In prior research, features that pop out for adults have been easier for infants to discriminate than have features that do not pop out for adults (e.g., Bhatt, 1997; Bhatt & Bertin, 2001; Bhatt, Bertin, & Gilbert, 1999; Colombo, Ryther, Frick, & Gifford, 1995; Quinn & Bhatt, 1998; Rovee-Collier, Hankins, & Bhatt, 1992). We examined whether, similarly, it would be easier for infants to detect concave elements among convex distractors than to detect convex elements among concave distractors in visual arrays. If this is the case, then it would suggest that for infants, as for adults, concavities are more salient than convexities. This, in turn, would suggest that concavities are likely to be meaningful sources of information for object perception during infancy as they are during adulthood (Feldman & Singh, 2005; Singh & Hoffman, 2001).

In Experiments 3 and 7, we tackled another issue pertaining to concavity–convexity discrimination. Concavities and convexities are defined only in relation to objects (i.e., closed forms); contour curvatures that point into the object are concavities, whereas those that point out are convexities (Elder & Zucker, 1993, 1994, 1998; Hulleman et al., 2000; Wolfe, 2000). In the absence of closed contours, it is not possible to determine the sign of the curvature (i.e., whether the curvature is pointing into or out of the object) unless cues such as closure and proximity are used to organize the contours and mentally "construct" shapes. Thus, the detection of concavities among convexities is more difficult if contours are freestanding and do not belong to closed shapes (Elder & Zucker, 1993, 1994, 1998; Hulleman et al., 2000; Wolfe, 2000). In Experiments 3 and 7, we examined whether, as in the case of adults, concave elements among convex distractors are easier for infants to detect when these contours belong to closed shapes than when they are freestanding and do not belong to closed shapes.

Experiment 1

As noted previously, prior studies have revealed a correspondence, at least under certain circumstances, between pop-out in adults and discrimination during infancy; features that pop out for adults are easier for infants to detect than are features that do not (e.g., Bhatt, 1997; Bhatt & Bertin, 2001; Bhatt et al., 1999; Colombo et al., 1995; Quinn & Bhatt, 1998; Rovee-Collier et al., 1992). Bhatt and colleagues (1999), for instance, found that $5\frac{1}{2}$-month-olds detect an array of discrepant micropatterns embedded in a larger array when the discrepancy is based on features (e.g., red Xs among blue Xs and green Os) but not when the discrepancy is based on feature conjunctions (e.g., blue Os among blue Xs and green Os), thereby paralleling the finding in adults that features such as colors and shapes pop out, whereas conjunctions of such features do not. Colombo et al. (1995) found an asymmetry in infants' discrimination performance that was analogous to some pop-out asymmetries exhibited by adults (Treisman & Souther, 1985). They found that infants detected a Q among Os but did not detect an O among Qs (presumably due to the extra line present in Qs).

In Experiment 1, we relied on the correspondence between pop-out in adults and discrimination during infancy. We examined whether infants will detect concave elements among convex distractors (pop-out in adults) but fail to detect convex elements among concave distractors (effortful serial processing in adults).

Method

Participants

In this experiment, 28 $6\frac{1}{2}$-month-olds (mean age = 198.04 days, $SD = 11.67$, 12 boys and 16 girls) participated. The infants were recruited using birth announcements in newspapers and via word-of-mouth. These infants were predominantly Caucasians from middle-class families. An additional 2 infants did not complete the experiment due to fussiness.

Stimuli

The stimuli are illustrated in Fig. 1. During familiarization, infants were exposed to homogeneous 4×4 arrays of convex or concave elements (Fig. 1, Panels A and C). During the test, infants were tested with a familiar pattern paired with another in which 2 of the 16 elements were novel (Fig. 1, Panels B and D). Two sets of patterns were used. In one (*same extent* set), the sizes of the concave and convex elements were equated such that their top-to-bottom and left-to-right extents were the same. However, this meant that the overall contour lengths of the concave elements were greater than those of the convex elements (due to the greater lengths of the horizontal lines in the concave elements). So, another set of elements (*same contour* set) was used with the other half of the infants, and here the overall contour lengths were equated between the convex and concave elements by shrinking the concave elements vertically and horizontally such that the differences in the lengths of the horizontal lines of the concave and convex elements were accounted for by the overall smaller size of the concave elements. In other words, in one set of elements the overall (horizontal and vertical) extents of the concave and convex elements were equated, whereas in the other set of elements the overall contour lengths of the elements were equated. From the infant's position, each array of elements subtended roughly 17.63°. The convex elements in both the same extent and same contour conditions subtended roughly 2.29°, whereas the concave elements subtended 2.29° in the same extent condition and 1.78° in the same contour condition. The positions of the individual elements in the arrays were randomly displaced by 0.75° vertically and/or horizontally to avoid any accidental alignment of the edges. The angle of the concave/convex contours was 120°.

Apparatus and procedure

The apparatus and procedure were similar to those used in previous studies (e.g., Bhatt, Bertin, Hayden, & Reed, 2005; Hayden, Bhatt, & Quinn, in press). Each infant was seated on a parent's lap approximately 45 cm in front of a 45-cm computer monitor on which two patterns were presented. The only light in the test chamber was from the monitor. A Sony CCD-FX430 camera, located on top of the monitor, and a DVD recorder, located outside the test chamber, were used to monitor and record infants' looks.

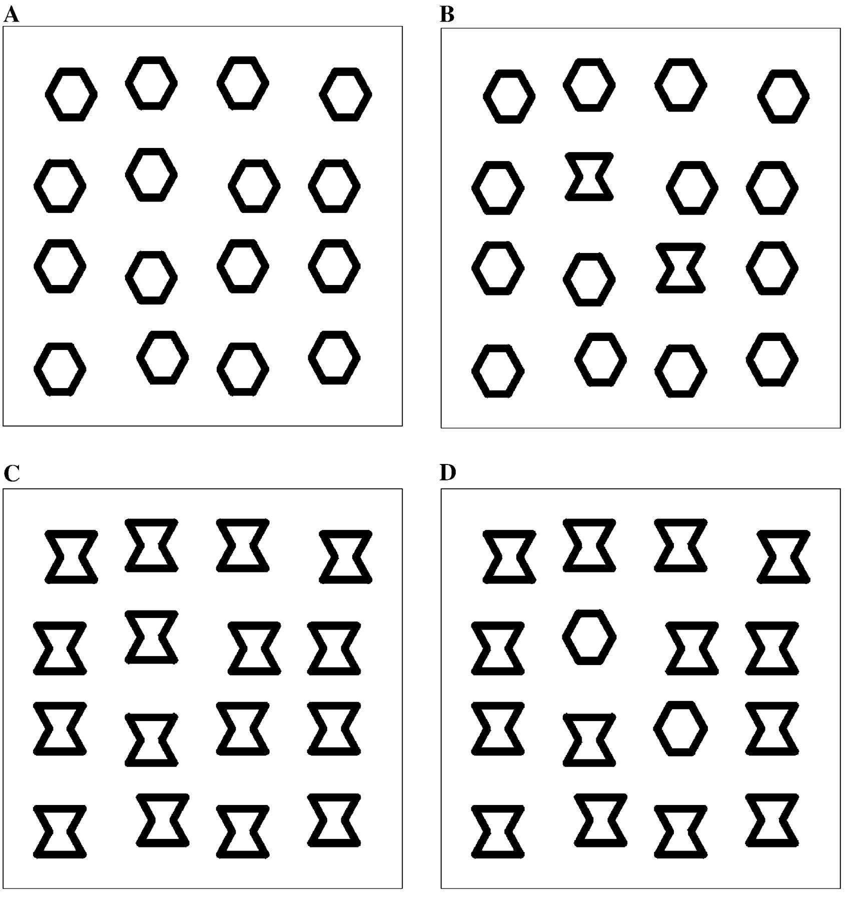

Fig. 1. Examples of the test stimuli used in Experiments 1, 2, 4, 5, and 6. Infants in the concave-among-convex conditions were tested for their preference between the homogeneous convex pattern (A) and the heterogeneous concave-among-convex pattern (B). Infants in the convex-among-concave conditions were tested for their preference between the homogeneous concave pattern (C) and the heterogeneous convex-among-concave pattern (D). The same extent stimuli are illustrated in this figure. In the same contour set, the concave elements were reduced in size to match the convex elements in total contour length.

A familiarization-paired comparison procedure was used to test the infants (Quinn & Bhatt, 2005a). Infants were exposed to four familiarization trials, each 20 s long, followed by two 10-s test trials. Each trial began with the presentation of a pulsating image on the center of the computer monitor to orient the infant toward the center. Once the infant looked at the center, the experimenter pressed a key to start the trial. The test trials followed immediately after the last familiarization trial. During the familiarization trials, infants were exposed to two identical exemplars of either the convex or concave homogeneous patterns. During the test trials, infants were exposed to a familiar pattern paired with a novel pattern in which two of the elements were discrepant (Fig. 1).

Half of the infants were familiarized to a homogeneous pattern of convex elements and tested with a pattern containing concave discrepant elements (*concave-among-convex* condition [Fig. 1, Panels A and B]). The other infants were familiarized to a homogeneous pattern composed of concave elements and tested with a pattern containing convex discrepant elements (*convex-among-concave* condition [Fig. 1, Panels C and D]). Also, half of the infants in each condition were familiarized and tested with the same extent stimuli, whereas the other half were tested with the same contour stimuli. The left–right position of the discrepant test pattern during the first test trial was counterbalanced across infants and switched from one test trial to the next.

As in prior experiments, infants' look durations were coded off-line by an observer who was unaware of the location of the novel test pattern and the test condition. The speed of the video display was reduced to 20% of normal speed for coding. Another naive experimenter coded the performance of eight randomly chosen participants. The Pearson correlation between the two observers' scores was .98.

Results

Box plot analyses (Tukey, 1977) of infants' look duration during the familiarization trials and their novelty preference scores (see below) revealed no outliers. Thus, all infants' data were included in the final analyses. Table 1 displays the mean looking times during familiarization. A Group (concave-among-convex or convex-among-concave) × Stimulus Set (same extent or same contour) × Trial (first two or last two) analysis of variance (ANOVA) revealed only a trial main effect, $F(1, 24) = 6.02$, $p < .05$. This suggests that

Table 1
Means (and standard errors) of fixation duration during familiarization trials and percentages novelty preference exhibited during test trials in Experiment 1

	First two familiarization trials (s)	Last two familiarization trials (s)
Concave-among-convex		
Same extent	15.17 (0.78)	13.50 (1.18)
Same contour	13.48 (0.73)	12.67 (1.25)
Combined	14.32 (0.56)	13.09 (0.83)
Convex-among-concave		
Same extent	13.15 (0.92)	11.92 (1.24)
Same contour	14.79 (0.65)	13.72 (1.31)
Combined	13.96 (0.59)	12.82 (0.92)
Preference (%) for novel pattern during test trials		
	M (SE)	t (vs. chance level of 50%)
Concave-among-convex		
Same extent	41.02 (3.15)	-2.84^*
Same contour	40.98 (6.68)	-1.35
Combined	41.00 (3.55)	-2.53^*
Convex-among-concave		
Same extent	50.96 (3.96)	0.82
Same contour	51.59 (5.20)	0.77
Combined	51.28 (3.14)	0.41

* $p < .05$ (two-tailed).

infants habituated from the first two trials to the last two trials. Moreover, infants' looking patterns did not differ as a function of whether they were being familiarized to the homogeneous convex pattern or to the homogeneous concave pattern. Also, look durations did not vary as a function of whether infants were being familiarized to the same extent or the same contour set of stimuli.

As in prior experiments, we computed a novelty preference score to examine infants' performance during the test. Each infant's look duration to the novel pattern was divided by the overall look duration to both patterns, and this ratio was then multiplied by 100 to arrive at a percentage novelty preference score. A mean score that is significantly different from the chance level of 50% was assumed to indicate discrimination, whereas a score that was not different from the level of 50% was assumed to indicate a lack of discrimination.

Table 1 displays the novelty preference scores of the two groups of infants. A Group (concave-among-convex or convex-among-concave) × Stimulus Set (same extent or same contour) ANOVA revealed a significant group main effect, $F(1, 24) = 948.56$, $p < .05$. Neither the stimulus set main effect nor the stimulus set × group interaction effect was significant, both Fs < 1. These results suggest that the test performance of the concave-among-convex group was different from that of the convex-among-concave group. Also, the performance of those tested with same extent stimuli did not differ from that of those tested with same contour stimuli.

Individual t tests revealed that the preference score of the concave-among-convex group was significantly different from the chance level of 50%, $t(13) = -2.53$, $p < .05$, whereas the score of the convex-among-concave group was not, $t(13) = 0.41$, $p > .50$ (Table 1). These results suggest that infants discriminated concave discrepant elements among the array of convex elements but failed to make the reverse discrimination. Thus, infants exhibited an asymmetry that was similar to that exhibited by adults.

Experiment 2

In Experiment 1, infants discriminated concave discrepant elements among convex distractors but failed to exhibit the reverse discrimination. However, this conclusion was based on a familiarity preference; the novelty preference score in the concave-among-convex condition was significantly *below* the chance level of 50%. Logically, this finding is indicative of discrimination in the concave-among-convex condition because any preference must have been engendered by the discrimination of the concave elements among the convex distractors in this condition. In contrast, the failure of infants in the convex-among-concave condition to exhibit any kind of preference (familiarity or novelty) suggests that infants did not detect the convex targets among concave elements. Prior research suggests that infants exhibit a familiarity preference when the stimulus patterns to which they are exposed are complex (e.g., Cohen, 2004; Fiser & Aslin, 2002; Hunter & Ames, 1988; Roder, Bushnell, & Sasseville, 2000), and that may be the reason for the infants' exhibition of a familiarity preference in the concave-among-convex condition of Experiment 1. Because the familiarity preference was unexpected, however, we decided to replicate this condition in Experiment 2 to verify that the result in Experiment 1 was not an aberration.

Method

Participants

In this experiment, 14 $6\frac{1}{2}$-month-olds (mean age = 205.07 days, $SD = 10.45$, 8 boys and 6 girls) participated. They were recruited in the same manner as those in Experiment 1.

Apparatus and procedure

The apparatus and procedure were the same as those used in Experiment 1. Infants were familiarized and tested with the same patterns and with the same procedure that was used in the concave-among-convex condition of Experiment 1.

Results and discussion

An examination of outlier information derived from box plots (Tukey, 1977, using SPSS version 13) revealed that the novelty preference score of 1 of the 14 infants was an outlier. This infant's novelty preference score was 80.75%, whereas the next highest score was only 49.91%. Thus, the final analysis did not include this infant's performance.

The results are shown in Table 2. Infants exhibited a decline in looking performance from the first two trials to the last two trials. However, a Trial (first two or last two) × Stimulus Set (same extent or same contour) ANOVA failed to reveal any significant main effects or interactions.

As in the case of the concave-among-convex group in Experiment 1, infants in this experiment exhibited a novelty preference score that was significantly less than the chance level of 50%, $t(12) = -2.96$, $p < .025$ (two-tailed). (Except for the outlier, every infant in this experiment [i.e., 13 of 14] exhibited a novelty preference score that was less than 50%. If the outlier is included, the resulting values are $t(13) = -1.30$, $p = .23$, two-tailed.) Thus, the results of the current experiment replicated the results obtained in the concave-

Table 2
Means (and standard errors) of fixation duration during familiarization trials and percentages novelty preference exhibited during test trials in Experiment 2

	First two familiarization trials (s)	Last two familiarization trials (s)
Concave-among-convex		
Same extent	15.69 (0.61)	14.65 (1.64)
Same contour	15.96 (0.52)	14.21 (1.43)
Combined	15.83 (0.43)	14.43 (1.24)
Preference (%) for novel pattern during test trials		
	M (*SE*)	*t* (vs. chance level of 50%)
Concave-among-convex		
Same extent	41.83 (3.15)	−1.98*
Same contour	44.12 (2.42)	−2.44*
Combined	42.89 (2.40)	−2.96**

* $p < .10$ (two-tailed).
** $p < .05$ (two-tailed).

among-convex condition of Experiment 1. In both cases, infants exhibited discrimination of discrepant concave elements among convex distractors by demonstrating a familiarity preference. These results confirm the finding in Experiment 1 that $6\frac{1}{2}$-month-olds discriminate concave elements among convex distractors but fail to make the reverse discrimination.[1]

Experiment 3

Consider Fig. 2. The patterns here are exactly the same as those that were used with the concave-among-convex groups in Experiments 1 and 2 (Fig. 1, Panels A and B) except for the fact that the individual pattern elements do not contain the two horizontal lines connecting the vertical contours and hence no longer are closed images. Note that the relevant contour differences that engendered discrimination in the concave-among-convex conditions of Experiments 1 and 2 are the same as those in the current patterns. Yet research suggests that such discrepancies are more difficult for adults to detect (Elder & Zucker, 1993, 1994, 1998; Wolfe, 2000) than are discrepancies of the sort used in Experiments 1 and 2.

One explanation for this is the argument that adults' attentional systems are geared toward objects, and hence adults are able to process attributes from the same object more effectively than they process the same attributes from different objects (e.g., Baylis & Driver, 1994; Humphreys & Donnelly, 2000; Vecera & Behrman, 2001). A related (but not exactly the same) explanation for the difficulty of detecting concave elements in patterns such as that shown in Fig. 2 is that concavities and convexities are defined in relation to closed forms (concavities point into the closed form, whereas convexities protrude out of the closed form), and in the absence of closed contours, it is not possible to define concavities and convexities (without using some organizing principles, such as closure and proximity, to mentally organize the disparate contours into shapes). This explanation predicts that infants will have difficulty in detecting the discrepant concave elements in this pattern because they also will not be able to easily discern concavities in the open shapes composed of freestanding contours. We tested this prediction in the current experiment.

Method

Participants

In this experiment, 14 $6\frac{1}{2}$-month-olds (mean age = 205.93 days, $SD = 9.31$, 7 boys and 7 girls) participated. They were recruited in the same manner as the infants in Experiments 1 and 2. In addition, 1 infant failed to complete the experiment due to fussiness.

[1] None of the analyses in Experiments 1 and 2 revealed a difference between the performance of infants in the same extent condition and that of infants in the same contour condition. However, it could be argued that the number of subjects in each condition in each of the experiments may have been too small to reveal a difference in performance. To examine this issue, we combined the participants in the concave-among-convex conditions of Experiments 1 and 2 (with the resulting *n*s of 14 and 13 in the same extent and same contour conditions, respectively) but still failed to find a statistically significant difference in performance during the tests, $t(25) = 0.68$, $p > .50$.

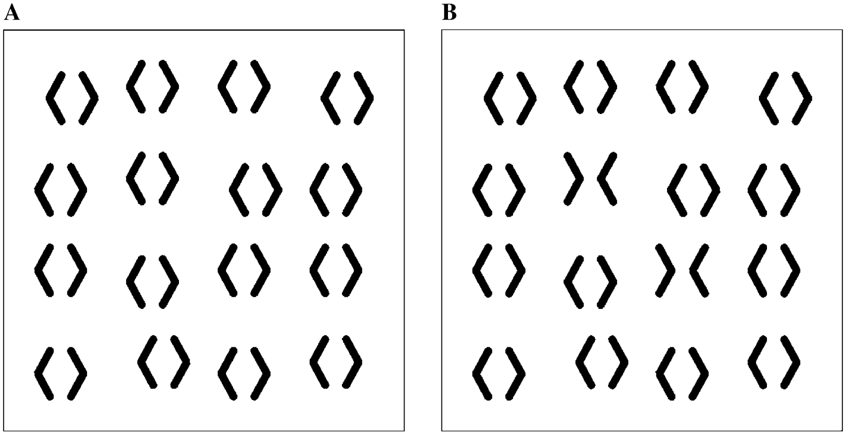

Fig. 2. The stimuli used in Experiments 3 and 7.

Stimuli

The stimuli used are shown in Fig. 2. They were exactly the same as those used in the concave-among-convex conditions of Experiments 1 and 2 except that the individual pattern elements were not closed shapes. Rather, only the concave and convex vertical contours remained from the stimuli used in Experiments 1 and 2. Also, the stimuli corresponded only to the same extent set used in Experiments 1 and 2 because, in the absence of horizontal lines, concave and convex elements had the same contour lengths.

Apparatus and procedure

The apparatus and procedure were the same as those used in Experiments 1 and 2. Infants were familiarized to the homogeneous convex line patterns (Fig. 2, Panel A) and tested with that pattern paired with another that contained concave elements among the convex distractors (Fig. 2, Panels A and B).

Results and discussion

Outlier analyses using box plots (Tukey, 1977) did not reveal any outliers. Thus, all infants' data were included in the final analyses. Infants' look duration during the familiarization trials are shown in Table 3. There was a significant decline in look durations from the first two familiarization trials to the last two familiarization trials, $t(13) = 2.56$, $p < .025$ (two-tailed). Thus, as in Experiment 1, infants in this experiment habituated to the homogeneous pattern before being tested.

Infants failed to discriminate the discrepant concave elements during the test (Table 3). Their novelty preference score was not significantly different from the chance level of 50%, $t(13) = 1.31$, $p > .20$. Infants failed to discriminate discrepant concave elements in this experiment, even though the relevant local information in the contours was the same as the information available to the infants when they successfully discriminated concave among convex elements in Experiments 1 and 2. However, the elements in the current experiment were not bounded individual entities, and hence concavities and convexities

Table 3
Means (and standard errors) of fixation duration during familiarization trials and percentages novelty preference exhibited during test trials in Experiment 3

	First two familiarization trials (s)	Last two familiarization trials (s)
Concave-among-convex		
Open contours	15.17 (0.87)	12.87 (0.99)
Preference (%) for novel pattern during test trials		
	M (*SE*)	*t* (vs. chance level of 50%)
Concave-among-convex		
Open contours	53.40 (9.69)	1.31*

* $p > .20$ (two-tailed).

were not readily defined here. This result suggests that infants, like adults, have difficulty discerning concavities and convexities in contours that do not belong to closed shapes.

Experiment 4

In this experiment and the subsequent experiments, we examined whether 5-month-olds, like the $6\frac{1}{2}$-month-olds in prior experiments, exhibit an asymmetry in the detection of concavities and convexities. We also examined whether 5-month-olds' discrimination of concavities among convexities is a function of whether the contours belong to closed shapes or are freestanding. We studied 5-month-olds because there have been suggestions in the literature that infants younger than 6 months of age might not be sensitive to certain kinds of edge information. Kellman and Shipley (1991; see also Kellman, 1996; Kellman and Arterberry, 1998) distinguished between edge-sensitive and edge-insensitive modes of perceptual processing and suggested that the edge-insensitive system is a "primitive" process that is available early in life, perhaps even at birth. In contrast, the edge-sensitive system is thought to be unavailable during the first 6 months of life (but see also Hayden et al., in press; Johnson, 2000; Kavsek, 2002; Needham & Ormsbee, 2003; Quinn & Bhatt, 2005b). The edge-insensitive process is thought to function on the basis of common fate (generally common movement), whereas the more mature edge-sensitive system is thought to tap into properties of edges such as relatability. Experiments 1 and 2 revealed that $6\frac{1}{2}$-month-olds are sensitive to concavities in objects' edges. Given the assumption in Kellman's model that edge-based properties are not available to infants younger than 6 months of age (Kellman, 1996; Kellman & Arterberry, 1998; Kellman & Shipley, 1991), would 5-month-olds tested in the same manner as $6\frac{1}{2}$-month-olds fail to discriminate concavities? This was the question addressed in the current experiment.

Method

Participants

In this experiment, 16 5-month-olds (mean age = 152.13 days, $SD = 7.17$, 8 boys and 8 girls) participated. They were recruited in the same manner as the infants in previous experiments. In addition, 1 infant did not complete the experiment due to fussiness, and the data from 1 other infant were discarded because he had a position preference (i.e., >90% of looking to one side during the experiment).

Stimuli

The stimuli used were the same as those used in the concave-among-convex condition in Experiments 1 and 2.

Apparatus and procedure

The apparatus and procedure were the same as those used with the $6\frac{1}{2}$-month-olds in Experiments 1 and 2. As in the concave-among-convex condition of Experiments 1 and 2, infants were familiarized to homogeneous patterns with convex elements and tested with concave elements embedded among convex elements. We did not run the reverse condition (convex-among-concave) in this experiment because this was an initial experiment, and we wanted to know whether these younger infants would even detect concave elements among convex distractors.

Results and discussion

Outlier analyses using box plots (Tukey, 1977) did not reveal any outliers. Thus, all participants' data are included in the following analyses. Infants' look durations during the familiar trials and their novelty preference scores during the test trials are shown in Table 4. Although there was a decline in looking times from the first two trials to the last two trials, a Trial (first two or last two) × Stimulus Set (same extent or same contour) ANOVA failed to reveal any significant main effects or interactions. However, as demonstrated in Experiment 2, it is not necessary for infants to exhibit evidence of habituation to discriminate novel stimuli in a familiarization/novelty preference procedure (see also Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002).

The 5-month-olds in this experiment failed to detect concave elements among convex elements, as indicated by novelty preference scores that were not significantly different

Table 4
Means (and standard errors) of fixation duration during familiarization trials and percentages novelty preference exhibited during test trials in Experiment 4

	First two familiarization trials (s)	Last two familiarization trials (s)
Concave-among-convex		
Same extent	15.05 (0.96)	14.26 (1.66)
Same contour	15.81 (1.11)	12.86 (1.31)
Combined	15.43 (0.43)	13.56 (1.15)
Preference (%) for novel pattern during test trials		
	M (*SE*)	*t* (vs. chance level of 50%)
Concave-among-convex		
Same extent	49.95 (5.21)	0.99*
Same contour	51.51 (4.62)	0.75*
Combined	50.73 (3.37)	0.83*

* $p > .70$ (two-tailed).

from the chance level of 50%, $t(15) < 1$. Also, there was no difference in performance between infants tested with the same size set and same contour set, $t(14) < 1$.

The results of this experiment suggest that there may be a developmental change during infancy in the processing of contour information: Whereas $6\frac{1}{2}$-month-olds, like adults, attend to concavities in contours, 5-month-olds do not. This result supports the Kellman model of perceptual development, which assumes that infants younger than 6 months of age do not have access to nuanced aspects of edge properties. However, before determining that infants younger than 6 months of age are absolutely unable to discern concavities in objects' contours, we wished to examine whether other test procedures would reveal sensitivity to concavities even in 5-month-olds.

Experiment 5

Reed, Hayden, and Bhatt (2005) reported a study based on an expectancy-based procedure in which $3\frac{1}{2}$- and 5-month-olds exhibited strong discrimination. In this procedure, infants were exposed to two stationary patterns at the beginning of each trial. After a certain period of time (which varied across trials), one of the patterns began to move across the computer monitor or shrank and expanded. Reed and colleagues (2005) reported that infants learned to look at the moving/expanding pattern prior to the movement/change. In other words, infants learned to associate one of two patterns with an interesting change and, across trials, began to look at the pattern before the change occurred. The fact that infants began to look preferentially toward one pattern than toward the other pattern provides a way of examining discrimination during infancy. We decided to use this procedure to examine whether 5-month-olds detect concave elements among convex elements and not vice versa. We reasoned that, at the very least, the use of this new procedure would provide convergent evidence for the developmental change that we found in Experiment 4.

Method

Participants

In this experiment, 16 5-month-olds (mean age = 152 days, $SD = 4.67$, 7 boys and 9 girls) participated. They were recruited in the same manner as the participants in the previous experiments. In addition, 1 infant did not complete the experiment due to fussiness.

Stimuli

The stimulus patterns used were the same as those used in the concave-among-convex conditions of Experiments 1, 2, and 4 (Fig. 1). Half of the infants were tested with the same extent set, and the other half were tested with the same contour set.

Apparatus and procedure

The apparatus was the same as that used in previous experiments. Infants were tested using an expectancy-based procedure (Reed et al., 2005). On each of 16 trials, the infant's attention was first directed to the center of the monitor by a pulsating red circle/green square image. Once the infant's gaze was directed to the center, the homogeneous pattern (consisting of convex elements) was presented on one side and a pattern containing concave elements among convex distractors was presented on the other side. The left–right locations of the two patterns were determined quasi-randomly, with the proviso that each pattern appear in each location on half of the trials and that a particular pattern did not appear on the same location more than twice in a row. The patterns remained stationary for a designated period of time; this time period was 8 s on even-numbered trials and 2 s or 4 s (chosen randomly) on odd-numbered trials. At the end of the stationary period, the pattern with the discrepant elements began to move or shrink/expand. (We chose not to counterbalance movement between the homogeneous and heterogeneous patterns so as to maintain the parallel with the familiarization/novelty preference procedure used in Experiments 1–3, where the discrepant patterns were seen only during the test as novel patterns and infants were expected to look longer at these patterns.) Three different kinds of zigzag and circular movements and a shrinking/expanding change were used. Four different melodies accompanied these changes. Each of these four types of changes was used once every 4 trials in a random order across the 16 trials. The movement and shrinkage/expansion changes and the accompanying sounds lasted for 6 s. After this, the two patterns remained stationary for 2 s.

The dependent measure we used was the looking preference during the 8 s on even-numbered trials in which the patterns remained stationary prior to the change. We measured the proportion of the looking toward the two patterns that was devoted to the discrepant pattern (the pattern that moved or shrank/expanded after this period). Coding was conducted off-line, and the video was slowed to 25% of normal speed for this purpose. Another observer coded the data from five randomly chosen infants to document the reliability of the coding. The Pearson correlation between the two coders was .97.

Results

As in Reed and colleagues (2005), the dependent measure was the preference for the concave-among-convex pattern during the 8-s stationary period in each of the eight even-numbered trials. We computed a preference score for each infant for each trial. This score was arrived at by dividing the look duration toward the concave-among-convex pattern by the total look duration toward both patterns and multiplying this proportion by 100 to get a percentage preference measure. We then took the average of two consecutive 8-s trials to compute the score for each of four blocks and analyzed the resulting data. A Trial Block (2–4, 6–8, 10–12, or 14–16) × Stimulus Set (same extent or same contour) ANOVA failed to reveal any main or interaction effects. Thus, infants' performance did not differ as a function of trials, nor was it affected by the type of stimuli used. Thus, in the following analyses, we collapsed performance across all trial blocks and across the type of stimuli used.

Table 5 shows infants' average preference scores across all trials. Infants exhibited a preference for the homogeneous pattern, $t(15) = -2.87$, $p < .02$ (two-tailed). The fact that infants exhibited a preference indicates that the infants had discriminated a difference between the homogeneous pattern containing only convex elements and the pattern containing concave among convex elements. Thus, 5-month-olds exhibited evidence of discrimination of concave among convex elements when they were tested using the expectancy-based procedure. In the General Discussion later, we discuss the reasons

Table 5
Means (and standard errors) of percentages preference for the changing pattern in Experiment 5

	M (SE)	t (vs. chance level of 50%)
Concave-among-convex		
Same extent	44.94 (2.33)	-2.17^{**}
Same contour	46.81 (1.77)	-1.79^{*}
Combined	45.87 (1.43)	-2.87^{***}

* $p < .15$ (two-tailed).
** $p < .10$ (two-tailed).
*** $p < .05$ (two-tailed).

why 5-month-olds discriminated concave among convex elements when the expectancy procedure was used in this experiment (and the next one) but not when the familiarization-paired comparison procedure was used in Experiment 4.

Experiment 6

The results of Experiment 5 suggest that even 5-month-olds might be sensitive to the presence of concave elements among convex distractors. However, this finding was based on an unexpected result, namely that infants exhibited a preference for the homogeneous pattern containing only convex elements, even though it was the pattern with the concave discrepant elements that underwent the interesting change. Thus, in Experiment 6, we attempted to replicate the finding of Experiment 5. In addition, we examined whether 5-month-olds would exhibit an asymmetry in the detection of concavity and convexity. That is, would 5-month-olds, like $6\frac{1}{2}$-month-olds in Experiment 1, detect concave elements among convex distractors but fail to detect convex elements among concave distractors under the same conditions? We examined this issue in the current experiment using the expectancy-based procedure employed in Experiment 5.

Method

Participants

In this experiment, 32 5-month-olds (mean age = 151.8 days, $SD = 6.05$, 15 boys and 17 girls) participated. They were recruited in the same manner as the infants in the previous experiments. The data from 2 other participants were not used due to fussiness ($n = 1$) or failure to look at either of the patterns on more than four trials ($n = 1$).

Stimuli

The stimuli were the same as those used during the test in Experiment 1 (Fig. 1). Half of the infants were exposed to the homogeneous convex and the heterogeneous concave among convex patterns, and the other half were exposed to the homogeneous concave and the heterogeneous convex among concave patterns. Also, half of the infants in each group were tested on the same extent set, and the other half were tested on the same contour set.

Apparatus and procedure

The apparatus and procedure were the same as those used in Experiment 5. For the concave-among-convex group, the concave among convex heterogeneous patterns were the changing (moving and shrinking/expanding) patterns. For the convex-among-concave group, the convex among concave heterogeneous patterns were the moving patterns.

Results

Outlier analyses using box plots (Tukey, 1977) indicated no outliers. Thus, the data from all infants were included in the final analyses. The results can be seen in Table 6. A Group (concave-among-convex or convex-among-concave) × Stimulus Set (same extent or same contour) × Trial Block (1–4, 5–8, 9–12, or 13–16) ANOVA revealed only a significant group main effect, $F(1, 28) = 5.42$, $p < .05$. Thus, the performance of the concave-among-convex group differed from that of the convex-among-concave group. Performance did not differ as a function of trial blocks, nor did it differ as a function of whether infants were tested on the same extent or same contour stimuli.

Individual t tests revealed that infants in the concave-among-convex condition discriminated between the homogeneous convex and heterogeneous concave among convex patterns; their average preference score was significantly different from the chance level of 50%, $t(15) = -4.78$, $p < .001$ (Table 6). As in Experiment 5, infants in this condition preferred the unchanging homogeneous convex pattern. In contrast, infants in the convex-among-concave condition failed to exhibit any evidence of discrimination, $t(15) = -1.01$, $p > .30$.

The results of the current experiment replicated the findings of Experiment 5 in that infants in the concave-among-convex condition exhibited discrimination in the form of a preference for the unchanging homogeneous convex pattern. More significantly, the results indicated that 5-month-olds, like $6\frac{1}{2}$-month-olds, discriminate concave elements among convex distractors under conditions in which they fail to discriminate convex elements among concave distractors. This asymmetry suggests that concavities play a special role in infants' perception of contours even by 5 months of age.

Table 6
Means (and standard errors) of percentages preference for the changing pattern in Experiment 6

	M (*SE*)	*t* (vs. chance level of 50%)
Concave-among-convex		
Same extent	43.88 (2.40)	-2.54^{**}
Same contour	37.47 (2.75)	-4.56^{**}
Combined	40.67 (1.95)	-4.78^{**}
Convex-among-concave		
Same extent	47.33 (2.33)	−0.82
Same contour	48.02 (3.49)	−0.56
Combined	47.68 (2.31)	−1.01

** $p < .05$ (two-tailed).

Experiment 7

The results of Experiments 1 and 3 revealed that although $6\frac{1}{2}$-month-olds can discriminate concave elements among convex distractors, they are unable to discern this difference if the elements are open contours (cf. Figs. 1 and 2). The absence of closed contours precludes the definition of concavity and convexity because these contour changes are defined with respect to the inside versus outside of objects (Wolfe, 2000). In the current experiment, we examined whether 5-month-olds, like $6\frac{1}{2}$-month-olds in Experiment 3, will also fail to discriminate concave among convex elements if the elements are not closed shapes.

Method

Participants

In this experiment, 16 5-month-olds (mean age = 155.31 days, $SD = 5.83$, 8 boys and 8 girls), recruited in the same manner as infants in the previous experiments, participated. In addition, 1 infant did not complete the experiment due to fussiness.

Stimuli

The stimulus patterns were the same as those used in Experiment 3. They were identical to the patterns used in the concave-among-convex conditions of Experiments 5 and 6 (and of Experiments 1, 2, and 4) except that the horizontal lines that rendered the individual elements into bounded closed elements were removed. Thus, the critical information pertaining to concavity and convexity of the contours remained, but the individual elements no longer were closed shapes.

Apparatus and procedure

The apparatus and procedure were the same as those used in Experiments 5 and 6. As in those experiments, the heterogeneous concave among convex pattern was the changing pattern in this experiment.

Results and discussion

There were no outliers according to box plot outlier analyses (Tukey, 1977). Hence, all infants' data were included in the final analyses. A Trial Block (2–4, 6–8, 10–12, or 14–16) ANOVA failed to reveal any difference in performance as a function of trials. Hence, in the following analysis, infants' performance was collapsed across trials. Infants' average preference score was 48.26 ($SE = 1.54$). Infants failed to discriminate a change. Their overall mean score was not significantly different from the chance level of 50%, $t(15) = -1.12$, $p > .25$. Thus, the difference that infants discriminated in Experiments 5 and 6 was not detected when the elements in the patterns were not closed shapes, such that concavity and convexity could not be readily defined.

Thus, the combined results of Experiments 5, 6, and 7 paralleled those of Experiments 1, 2, and 3. The 5-month-olds, like the $6\frac{1}{2}$-month-olds, exhibited an asymmetry in the detection of concavities and convexities, and their discrimination of concavities among convexities was affected by whether the contours belonged to open or closed shapes.

General discussion

Adults derive object parts by attending to concavities (negative minima of curvatures) in shape contours. The current results suggest that infants as young as 5 months of age treat concavities as special regions of object contours. Infants exhibited an asymmetry in the detection of concavities and convexities: 5- and $6\frac{1}{2}$-month-olds detected discrepant concave elements among convex distractors in visual arrays but failed to detect discrepant convex elements among concave distractors. This asymmetry is analogous to the finding that adults' detection of concave targets among convex distractors in visual search tasks is rapid and efficient, but the detection of convex targets among concave distractors is laborious and inefficient (Hulleman et al., 2000; Wolfe & Bennett, 1997; Xu & Singh, 2002). The current study also demonstrated that infants' detection of concavity is impaired if the contours that define concavity and convexity are not part of closed shapes. This result indicates that for infants, as for adults, concavities and convexities are defined more readily in the context of closed shapes. Taken together, the results suggest that at least rudimentary aspects of part perception from shape contours are available during infancy.

The finding that adults detect concave elements among convex distractors very efficiently in visual search studies (i.e., search slopes do not vary much as a function of number of distractors) has been used to argue that concavities are fundamental features (e.g., Hulleman et al., 2000; Wolfe, 2000). However, there is controversy in the literature as to whether there is a limited set of fundamental features and whether efficient (parallel) search is an index of "featurehood" (e.g., Joseph, Chun, & Nakayama, 1997; Pashler, 1998; Wolfe, 1994, 2000; Xu & Singh, 2002). Moreover, features may be learned, and as such, what constitutes the set of fundamental features might be open for debate (Goldstone, 2003). Also, the current experiments did not examine whether infants' detection of concave elements among convex distractors was a result of pop-out or parallel processing. Hence, it would be premature to argue that the greater salience of concavities than convexities seen in the current experiments arose from the fact that concavities are fundamental features during infancy. Future studies will need to examine the exact nature of the differences underlying the processing of concavities versus convexities during infancy and how they relate to adults' processing of these kinds of contour information.

As noted previously, prior research suggests that young infants attend to contours. Bhatt and Bertin (2001) found, for instance, that infants as young as 3 months of age are sensitive to 3-D junction cues that adults use to derive 3-D structure and orientation. Prior research also suggests that vertices in contours are important for object recognition during infancy (Frick & Colombo, 1996). The current research extends these findings to demonstrate that regions of concave curvatures in contours are significant for infants as young as 5 months of age. A number of additional steps beyond the detection of concavities underlie part decomposition during adulthood (e.g., Biederman, 1987; Singh et al., 1999; Singh & Hoffman, 2001). Future research will need to examine the development of these other aspects of part decomposition.

An issue that is worth considering is the finding that infants exhibited a preference for homogeneous convex patterns over heterogeneous concave among convex patterns in four experiments involving two different procedures and two different age groups (Experiments 1, 2, 5, and 6). This preference may have resulted from the characteristics of the procedures used to test infants. As noted previously, for instance, infants tend to exhibit a familiarity preference when tested on complex stimuli using the familiarity/novelty preference procedure, and this may have led infants to prefer to look at the less complex homogeneous convex pattern in our experiments (e.g., Cohen, 2004; Fiser & Aslin, 2002; Hunter & Ames, 1988; Roder et al., 2000). Alternatively, it is possible that infants have a preference for convex elements over concave elements and that this may have led them to prefer the pattern with more convex elements (the homogeneous convex pattern over the concave among convex heterogeneous pattern). However, such a preference cannot account for the discrimination asymmetry exhibited by the infants in these experiments (i.e., the detection of concave elements among convex distractors but not vice versa). This is because if infants' performance had been due solely to a preference for convex elements, then they should have exhibited a novelty preference in the condition in which the discrimination was between a pattern containing only concave elements and a pattern containing convex elements among concave distractors (the convex-among-concave conditions of Experiments 1 and 6). However, infants in these conditions failed to exhibit any discrimination, indicating that they had difficulty in discerning the discrepant convex elements among concave distractors. In contrast, they had no difficulty in discriminating concave elements among convex distractors (the concave-among-convex conditions of Experiments 1, 2, 5, and 6).

A more complex account that assumes that infants have a preference for convex elements over concave elements *in addition to* difficulty in detecting convex elements among concave elements but not in detecting concave elements among convex elements could explain the results. According to this account, infants in the concave-among-convex conditions preferred the homogeneous convex pattern because they could discern the concave elements among convex distractors in the heterogeneous patterns and, because there was a greater number of convex elements in the homogeneous pattern, looked longer at this pattern. In contrast, infants in the convex-among-concave conditions did not exhibit a preference because, under the conditions of the current experiments, they could not discern the convex elements among concave distractors in their heterogeneous patterns. Of course, such an account is consistent with our conclusion that the results of the current experiments document a genuine asymmetry in infants' ability to detect concavities and convexities.

A question that arises is whether the familiarity preference exhibited in the concave-among-convex conditions and the lack of any preference in the convex-among-concave conditions of Experiments 1 and 2 would change if infants are exposed to the familiar patterns for longer durations before being tested. It is hard to predict what would happen if infants were exposed to stimuli for longer durations. The results in the expectancy procedure used in Experiments 5 to 7 paralleled those in the familiarity/novelty preference procedure in Experiments 1 to 4, even though in the former procedure infants were exposed to stimuli for a total of 216 s, which is more than 2.5 times the 80 s of exposure during familiarization in the familiarity/novelty preference procedure. Moreover, it is unlikely that performance in the expectancy procedure was affected by differential levels of familiarity/novelty given that infants were exposed to both patterns throughout all trials. Increasing the exposure duration further in the familiarity/novelty preference procedure could result in the infants in the concave-among-convex conditions exhibiting a novelty preference. It is also possible, however, that infants would continue to exhibit a familiarity preference or would merely be pushed to exhibit a null preference because the tendency for novelty preference would still need to compete with a preference in the opposite direction for the convex elements. In any case, we were trying to examine the relative difficulty of processing concave-among-convex elements and vice versa and found that, under the conditions of the current experiments, infants processed concave among convex elements more easily than the reverse. This does not necessarily imply that infants are absolutely unable to detect convex elements amid concave distractors. There may be conditions (e.g., extended familiarization, more pronounced angles) under which both concave-among-convex and convex-among-concave patterns may be discriminated (perhaps with evidence indicating that the former discrimination is still easier than the latter discrimination).

The fact that infants as young as 5 months of age are sensitive to concavities is significant because some researchers have suggested that infants younger than 6 months of age are unable to use edge-sensitive mechanisms of 3-D object perception (e.g., Arterberry, 2001; Kellman, 1996; Kellman & Arterberry, 1998). Recall that when a familiarity/novelty preference procedure was used, $6\frac{1}{2}$-month-olds discriminated concave elements among convex distractors (Experiments 1 and 2), but 5-month-olds failed to do so (Experiment 4). However, the same discrepancy was discriminated by 5-month-olds when the expectancy-based procedure was used (Experiments 5 and 6). The two procedures differed in many ways; therefore, it is not possible to conclude that a particular difference contributed to the disparity in the findings. However, a critical difference between the procedures was that stimulus movement was part of the expectancy-based procedure, whereas only stationary stimuli were used in the familiarity/novelty preference procedure. There is evidence suggesting that cues from moving stimuli sometimes are more salient to infants than those from stationary stimuli (e.g., Kellman & Arterberry, 1998; Owsley, 1983; Yonas, Arterberry, & Granrud, 1987). Thus, the movement of stimulus patterns in the expectancy procedure may have contributed to the 5-month-olds' detection of concavity in the experiments that used that procedure. However, the preference measure that was used in these experiments involved performance during the 8 s at the beginning of even-numbered trials when the patterns were *stationary*. In other words, evidence of discrimination was obtained when the stimuli were not moving, meaning that infants could detect the difference between the homogeneous convex and concave-among-convex patterns in the absence of movement. Hence, any facilitating effects of stimulus movement/change (during the portions of the trials when the concave-among-convex pattern was moving and shrinking/expanding) on concavity discrimination would have needed to generalize to the stationary periods (cf. Kellman & Arterberry, 1998; Owsley, 1983; Yonas et al., 1987). Our intent in the current experiments was to address the question of whether infants as young as 5 months of age are sensitive to concavities in contours, and we were able to demonstrate this in the current study. Future studies will need to determine the exact conditions under which such sensitivity is exhibited and what this implies for models of perceptual development.

In a series of visual search studies, Elder and Zucker (1993, 1994, 1998) demonstrated the significance of closure for shape perception. In their studies, adults' processing of shape information was rapid for closed stimuli but slow for open stimuli. The finding in the current study indicating that infants detect concave elements among convex elements when the elements are closed shapes but not when they are freestanding open contours suggests that a similar role may be played by closure during infancy as well. As noted previously, a specific effect of open contours versus closed contours may be that concavities and convexities can be defined only when the inside/outside of objects can be identified.

Research by Pasupathy and Connor (2002) indicates that neurons in Area V4 of macaque monkeys respond to curvature changes in contours and that distinct subpopulations respond to concave contours versus convex contours. These findings suggest that even our physiology may be organized to use the significant information in objects' contours. Thus, theoretical, empirical, and physiological studies all point to the importance of contour concavities for object perception (e.g., Attneave, 1954; Biederman, 1987; Feldman & Singh, 2005; Hoffman & Richards, 1984; Marr & Nishihara, 1978; Singh et al., 1999). The current study examined infants' sensitivity to this information. The results suggest that infants as young as 5 months of age are ready to use the important information available in concave contours.

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Pictorial Cues and Three-Dimensional Information Processing in Early Infancy

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Adults derive 3-D information from 2-D images by initially processing local line junction cues and then combining information from many junctions. Prior research indicates that 3-month-olds are sensitive to 3-D cues in individual line junctions. In Experiment 1, we examined whether infants are sensitive to holistic combinations of line junctions that adults use to derive overall 3-D structure. Infants detected a misoriented shape in an array depicting 3-D blocks but not in 2-D patterns that contained all of the trilinear junctions of the 3-D shapes but without the connecting lines. Thus, like adults, infants exhibited sensitivity to holistic combinations of line junctions rather than to individual junctions. In Experiment 2, when confronted with two test patterns, one containing an individual novel element among 15 familiar elements and the other containing a single familiar element among 15 novel elements, infants preferred to look at the former pattern in the 3-D condition but at the latter pattern in the 2-D condition. Thus, akin to pop-out in adults, discrepancies in 3-D cues selectively engaged infants' attention. These results suggest that 3-month-olds are not only sensitive to holistic combinations of line junctions that adults use to derive 3-D information but also selectively attend to these 3-D cues in static images. © 2001 Academic Press

Key Words: 3-D perception; line junction cues; object structure; attention; infancy.

To function effectively in this world, organisms need to be able to derive the 3-D structure and spatial layout of objects from the 2-D information that is available in visual images. Indeed, research suggests that human adults readily derive 3-D information from static 2-D images (e.g., Enns, 1992; Enns & Rensink, 1991; Sun & Perona, 1996). The present study examined 3-month-olds' sensitivity to line junction cues in line drawings that adults use to derive 3-D structure and orientation information.

The starting points for this analysis of 3-D information processing in infancy were models of object perception that assume that edges and junctions are critical for the retrieval of object shape and spatial layout information (e.g., Biederman, 1987; Enns, 1992; Hoffman & Richards, 1984; Kellman & Shipley, 1991). Enns and Rensink's (1991; also see Enns, 1992) PRISM model has spe-

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cific proposals concerning the manner in which adults use line junctions in images to retrieve 3-D information about objects. Based on research in computational sciences (see Waltz, 1975; Winston, 1992), this model assumes that three kinds of trilinear junctions are possible in images of scenes containing polyhedral objects: T junctions, Y junctions, and arrow junctions (see Figs. 1A, 1C, and 1E). Arrow junctions are those in which one angle is greater than 180°; Y junctions are those in which the greatest angle is less than 180°; T junctions are those in which one angle is exactly 180°. T junctions typically correspond to surface occlusions and hence only indicate the relative depth of two objects; however, combinations of Y and arrow junctions can be used to determine the 3-D orientation of objects depicted by images. The PRISM model assumes that the visual system first estimates local occlusion and orientation information based on individual junctions and then goes through an iterative process that checks for consistency of these estimates with each other to determine the overall 3-D structure. An extensive series of experiments by Enns and Rensink (1990, 1991; also see Enns, 1992) suggests that adult humans indeed utilize line junction information to derive 3-D shape and orientation in the manner assumed by the PRISM model.

Given this model of 3-D shape and orientation perception, the question arises as to how the ability to derive such 3-D information develops in humans. Yonas and Arterberry (1994) found that 7.5-month-old infants attend more to lines that form edges and corners of objects than to those that are surface markings. Thus, this study suggested that by at least 7.5 months of age, infants are sensitive to some of the cues that adults use to specify the 3-D shapes and orientations of objects. Bhatt and Waters (1998) found that 3-month-old infants are sensitive to discrepancies in patterns of images that appear to be 3-D blocks illuminated from the top but fail to detect comparable changes in images that appear to be flat 2-D images. Similarly, Bhatt (1999) found that 3-month-olds are sensitive to changes in the orientation of line drawings that to adults appear to have 3-D structure (Fig. 1B) but are not sensitive to comparable changes in line drawings that do not have a ready 3-D structure interpretation (Figs. 1D and 1F). These results led Bhatt and his colleagues to conclude that sensitivity to 3-D cues in static images is developed by at least 3 months of age.

In the current set of experiments, the nature of infants' sensitivity to line junction cues was explored. In Experiment 1, we examined whether infants are sensitive solely to individual line junction 3-D cues or whether they process combinations of line junctions. Recall that, according to the PRISM model proposed by Enns and Rensink (1991), adults derive the 3-D structure and orientation of objects by initially processing information in local line junctions and then iteratively combining this information to derive overall structure. The sensitivity to 3-D junction information exhibited by 3-month-olds in Bhatt and Waters (1998) and in Bhatt (1999) could have reflected the processing of information at individual line junctions rather than the processing of holistic combinations of line junctions that determine 3-D structure for adults. In Experiment 1 of the current study, we examined whether infants' processing of 2-D images that appear to

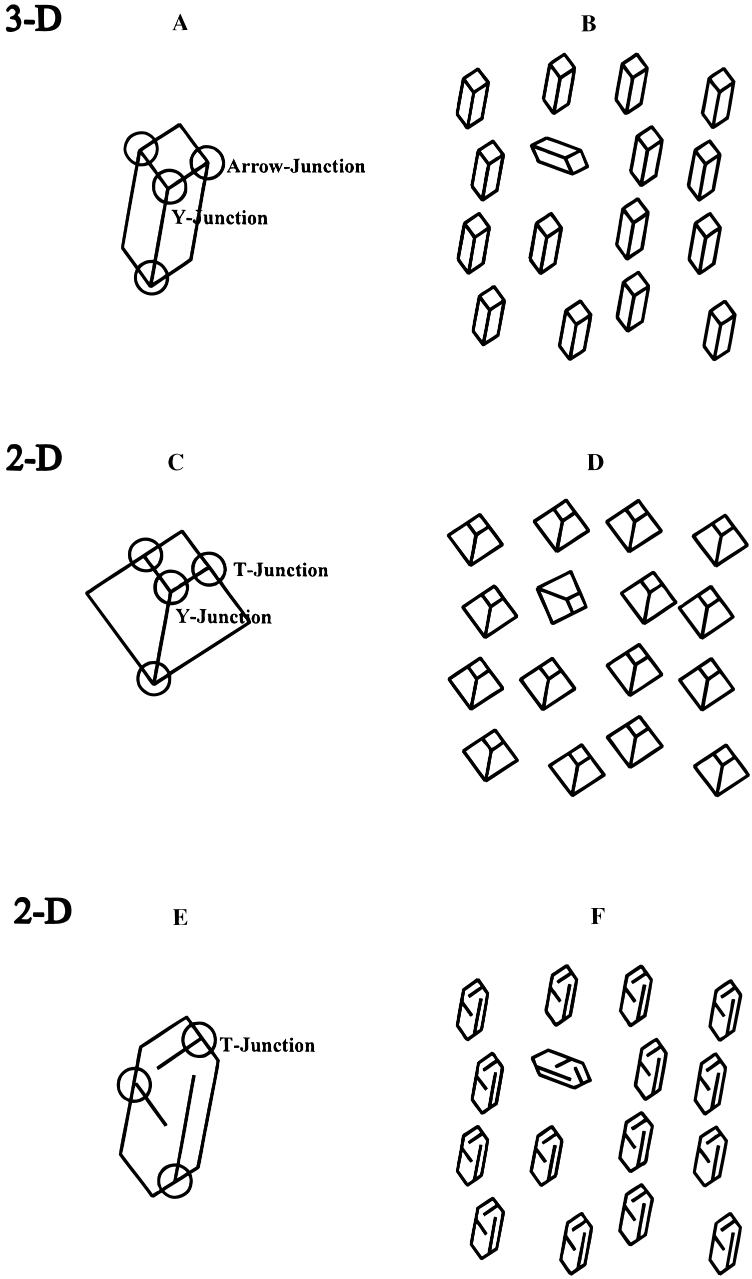


FIG. 1. Adults utilize arrow, Y, and T junctions to derive the 3-D structure and orientation of objects from 2-D images. Some 2-D images depict constellations of line junctions that readily signal 3-D structure (e.g., A), whereas other images do not lend themselves to easy 3-D interpretations (C and E). Bhatt (1999) found that 3 month olds discriminate changes in the orientation of line drawings that to adults appear to have 3-D structure (B) but do not respond to comparable changes in line drawings that do not have a ready 3-D structure interpretation (D and F).

have 3-D structure stops at the initial level of processing of local junctions or whether infants go beyond this phase to process relational information among many line junctions.

A second issue examined in the current research concerned the question of whether discrepancies based on 3-D cues in visual arrays engage infants' attention. Prior research has demonstrated that, akin to the effects of pop-out in adults, discrepancies based on fundamental features, such as line crossings and orientation, attract and engage infants' attention (Bhatt, 1997; Bhatt, Bertin, & Gilbert, 1999; Quinn & Bhatt, 1998; Rovee-Collier, Hankins, & Bhatt, 1992). Prior research also suggests that discrepancies in images that appear to have 3-D structure pop-out for adults (e.g., Enns & Rensink, 1990, 1991; Ramachandran, 1988; Sun & Perona, 1996). Thus, in the present study, we examined whether discrepancies in 3-D cues also attract and engage infants' attention in the same manner as discrepancies in simple fundamental features such as line orientation. If evidence of such attentional engagement were obtained, then it would suggest that, early in life, we selectively attend to ecologically relevant complex properties of objects.

EXPERIMENT 1

As noted earlier, research by Bhatt and Waters (1998) and by Bhatt (1999) suggests that infants as young as 3 months of age are sensitive to 3-D line junction cues in static 2-D images. One question that follows is whether, like adults, infants are sensitive to holistic combinations of line junctions or whether they are sensitive solely to local line junction cues and are incapable of relating disparate line junctions. Note that 3-D shapes depicted by 2-D images contain a combination of Y and arrow junctions that, according to Enns and Rensink's (1991) PRISM model, are *combined* by adults to derive the 3-D structure and orientation of objects (see Fig. 1). It is possible that 3-month-olds can only process the trilinear junctions in the 3-D images as disparate entities and do not process combinations of these junctions.

Support for this possibility comes from the general finding in the literature that infants younger than 5 months of age are unable to derive the 3-D structure of objects in static 2-D images. Indeed, it is generally thought that sensitivity to monocular cues to 3-D structure (the kind found in static 2-D images) develops between 5 and 7 months of age (e.g., Kavsek, 1999; but see Caron, Caron, & Carlson, 1979; Slater & Morrison, 1985; for reviews, see Kellman, 1996; Kellman & Arterberry, 1998; Yonas, Arterberry, & Granrud, 1987). It is possible, therefore, that 3-month-olds are incapable of relating disparate trilinear junctions. While the fact that infants are sensitive to the line junction cues that later in development are used to derive 3-D structure is itself of interest, a finding that infants do not go beyond this phase to combine information from several line junctions would suggest a stage in the development of humans in which infants are sensitive to disparate monocular static cues for 3-D structure but are unable to complete the additional steps that are necessary to derive 3-D information.

We examined this issue in the current experiment by testing infants on patterns that contained the trilinear junctions that are thought to be critical for adults' derivation of 3-D structure but did not appear to be coherent 3-D objects. This approach was based on the finding by Enns and Rensink (1991, Experiment 6) that the rapid processing of 3-D cues by adults is deleteriously affected if lines that connected trilinear line junctions are erased. Enns and Rensink argued that this result indicates that 3-D processing involves not only the processing of local trilinear junctions but also the holistic relations among these junctions. Thus, in the current experiment, we used images that contained all of the trilinear junctions necessary to form 3-D images but did not contain the connecting lines that are necessary to derive 3-D structure (see Fig. 2). If infants discriminate a change solely because of discrepancies in the disparate individual junctions, then infants should discriminate comparable changes in these images also. If, on the other hand, 3-month-olds do engage in relational processing of line junctions, then infants should treat these images like 2-D images and not be sensitive to changes in an individual element of the arrays.

We used an infant-control habituation procedure (Horowitz, Paden, Bhana, & Self, 1972) in this experiment. In this procedure, infants are exposed to the familiarization stimuli until their looking times decline to a predetermined criterion. This ensures that infants under different conditions are habituated to an equivalent degree before being tested.

Method

Participants. Thirty-six full-term 3-month-olds (21 females, 15 males; mean age = 100.5 days; $SE = 1.17$ days) participated in this study. They were recruited using birth announcements in local newspapers and by word of mouth. Infants in this and the following experiment were predominantly Caucasian and from middle-class backgrounds. An additional 16 infants were excluded from this study for crying ($n = 11$), for falling asleep ($n = 1$), or for failing to sample both test stimuli ($n = 4$). An infant was deemed to have failed to sample both test stimuli if he or she failed to even glance at one of the stimuli. Consistent with the common practice in studies that use this procedure (see, for example, Frick, Colombo, & Allen, 2000; Ghim & Eimas, 1988; Slater & Morrison, 1985; Slater et al., 1990), data from infants who fail to sample both test stimuli were discarded in this study because it is impossible to ascertain preference between the two test patterns in the absence of any comparison between the two test patterns.

Stimuli. The stimuli were computer generated versions of the 3-D stimuli used by Bhatt (1999; *3-D stimuli*; see Fig. 2) and the same stimuli with missing contours such that the three arrow junctions and the Y junction are not combined to form 3-D shapes (*2-D Junction stimuli*; see Fig. 2). From the infants' viewpoint, each micropattern subtended roughly 2.86° of visual angle and each of the arrays subtended 17.06° × 17.06°. During testing, a familiar homogenous pattern was paired with a novel test pattern that contained a single misoriented discrepant micropattern surrounded by 15 familiar micropatterns (Fig. 2). Four different ver-

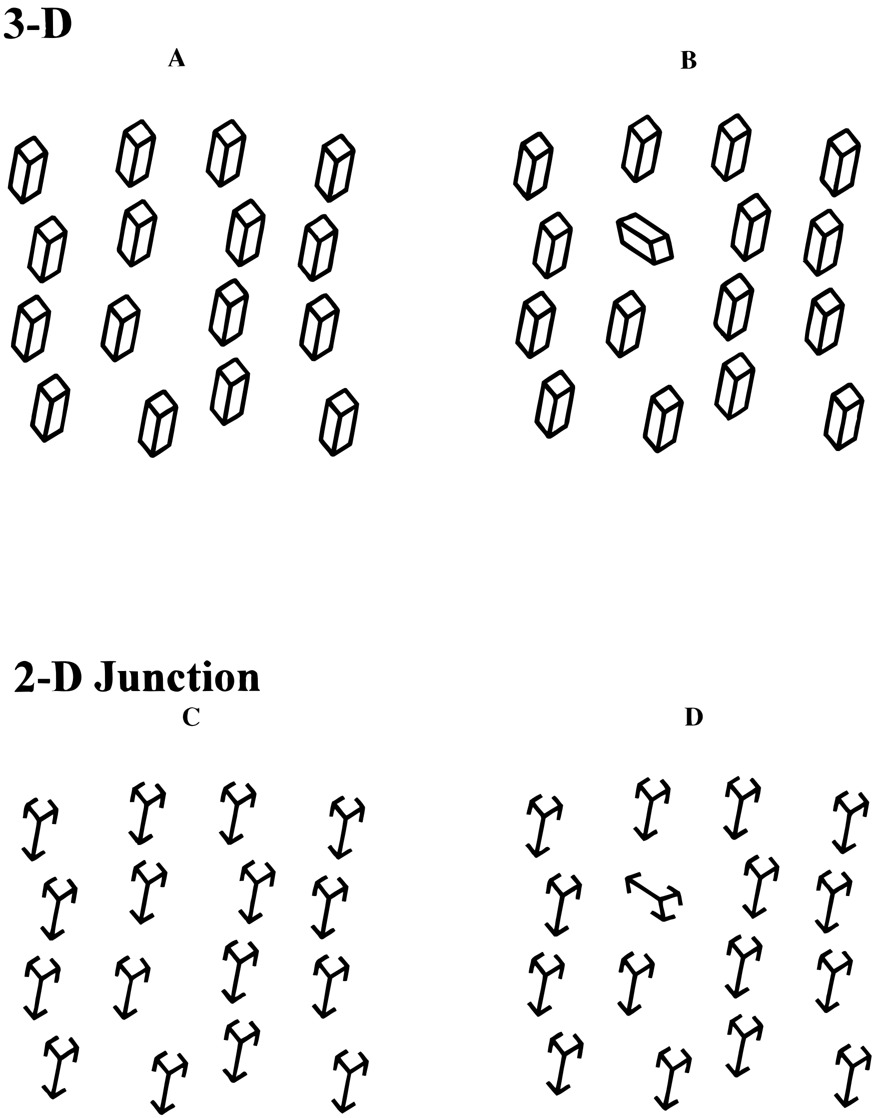


FIG. 2. Examples of the habituation and test patterns used in Experiment 1. Infants in the 3-D condition were habituated to two homogenous arrays of the kind displayed in A prior to being tested; infants in the 2-D junction condition were habituated to two homogenous arrays of the kind displayed in C prior to being tested.

sions of the familiarization and test stimuli were used in each condition. Specifically, the elements in the familiarization arrays were oriented at 80°, 170°, 260°, or 350°. The discrepant elements in the test arrays were oriented at 100° to the rest of the elements in the arrays. The position of the discrepant element in the array was varied across subjects, such that it was located at either the top left or the bottom right of the test pattern, diagonally one position away from the center of the array.

Apparatus and procedure. The apparatus and procedure were the same as those used by Bhatt et al. (1999, Experiments 4A and 4B). A 20-in. IBM monitor, located in the front wall of a darkened chamber, was used to display the stimuli. The participants were seated in an infant car seat at a distance of about 40 cm from the monitor. A Sony CCD-FX430 camera, located on top of the computer monitor, was used to record infants' gaze direction and duration. As noted above, an infant-control habituation procedure was used in this study. On each familiarization trial, two homogenous patterns were presented to the infant. These patterns remained on the screen until the infant looked away for 2 consecutive s or until a maximum of 60 s had elapsed. Such familiarization trials were repeated until the mean look duration during three consecutive trials for each infant was less than half of the mean look duration during the first three trials for the same infant or until the infant had gone through a maximum of 20 familiarization trials. Two infants in the 3-D group and 1 infant in the 2-D group went through the complete 20 familiarization trials without meeting the habituation criterion. Their data are included in the final analysis.

Immediately after the last familiarization trial, infants were exposed to two 10-s test trials, during which infants were exposed to two patterns, one of which was a familiar homogenous pattern and another which contained a single novel misoriented micropattern amidst familiar micropatterns (Fig. 2). Data coding of the test trial performance was conducted offline by an experimenter who was unaware of the left–right location of the test patterns. The performance of 12 randomly chosen participants was coded by another naïve experimenter to examine interobserver reliability. The average Pearson correlation between the two observers was 0.98 ($SE = .01$).

Results and Discussion

Table 1 displays the mean looking times during the first three and the last three habituation trials. A group (3-D, 2-D) × trial (first three, last three) ANOVA revealed a trial main effect, $F(1, 34) = 169.96$, $p < .001$. No other main or interaction effect was significant. Thus, while the infants exhibited a significant decline in looking times from the first three to the last three habituation trials (as required by the procedure), there was no evidence to suggest that the 2-D stimuli were treated any differently than the 3-D stimuli during the habituation phase of the experiment.

Table 1 also displays the preference scores exhibited by the two groups during the test. The preference score is the percentage of total looking toward the test patterns that was devoted to the pattern with the single novel element. Infants in the 3-D group looked more toward the pattern with the single novel micropattern, whereas infants in the 2-D Junction group did not exhibit a preference. Specifically, preference for the pattern with the single novel element was significantly *greater* than the chance level of 50% in the 3-D condition, $t(17) = 2.15$, $p < .05$, whereas this preference was not significantly different from the chance

TABLE 1
Mean (and Standard Error) of Fixation Duration during Habituation Trials and Percentage of Preference for the Array with the Single Novel Element during Test Trials in Experiment 1

	First three familiarization trials (seconds)	Last three familiarization trials (seconds)
3-D	46.92 (2.98)	20.98 (3.51)
2-D Junction	43.80 (3.75)	15.61 (2.01)

Preference (%) for array with single novel element during test trials

	M (*SE*)	*N*	*t* (vs chance)	*p* (two-tailed)
3-D	60.49 (4.87)*	18	2.15	<.05
2-D Junction	46.93 (4.05)	18	−0.76	>.05

Note. Asterisks indicate that the mean preference for the pattern with the discrepant novel element during the test was significantly different from the chance level of 50%.

level of 50% in the 2-D Junction condition, $t(17) = -0.76$, $p > .05$. Also, there was a significant difference between the preference scores of the two groups, $t(34) = 2.14$, $p < .05$.

Thus, infants discriminated a change in a pattern whose elements had a 3-D structure interpretation but not in a pattern whose elements had all of the critical trilinear junctions but without the connecting edges that made a 3-D structure interpretation possible. These results suggest that infants are sensitive to combinations of trilinear junctions. It has to be recognized that this sensitivity to combinations of trilinear junctions may not necessarily translate into complete 3-D form perception of the kind achieved by adults. The results do indicate, however, that infants go beyond the processing of individual line junctions and engage in at least one additional critical computation that is necessary to derive 3-D structure, namely, the combination of information from different trilinear junctions in 2-D images that depict a 3-D shape.

EXPERIMENT 2

In Experiment 2, we examined whether discrepancies based on 3-D cues attract and engage infants' attention. A considerable amount of research suggests that, when adults search for an object in a scene, certain objects are detected immediately (i.e., they "pop-out"), with search times that are independent of the number of other objects in the scene (i.e., parallel processing). In contrast, search for other types of objects is effortful, with search times increasing with increases in the number of objects in the scene. Many researchers have argued that these two types of searches reflect the functioning of the preattentive and attentive systems, respectively (for reviews, see Pashler, 1998; Treisman, 1993; Wolfe, 1998, 2000). It is thought that the preattentive system directs attention to information-rich areas of the visual scene, and information available in those areas is then processed more deeply using the attentional system.

Most studies on preattentive processing have dealt with simple one- or two-dimensional features, such as size, line segments, orientation, and various 2-D shapes ("fundamental features"), and it was assumed that only such simple features are processed by the preattentive system. However, research indicates that 3-D cues also pop-out for adults (e.g., Enns, 1992; Enns & Rensink, 1990, 1991; Ramachandran, 1988; Sun & Perona, 1996). That is, research suggests that adults rapidly and in parallel detect discrepancies in visual scenes composed of 3-D shapes. These results have led to the conclusion that ecologically relevant complex properties of objects that have to be computed by combining many simple features might also be rapidly available to the preattentive system.

Prior research suggests that, akin to the effects of pop-out in adults, discrepancies based on fundamental features, such as line crossings and line orientations, attract and hold 3-month-old infants' attention (Bhatt, 1997; Bhatt et al., 1999; Quinn & Bhatt, 1998; Rovee-Collier et al., 1992). Quinn and Bhatt (1998), for instance, found that 3 month olds familiarized with an array containing 25 micropatterns (e.g., +s) subsequently preferred a test array that contained a single novel micropattern (e.g., L) among 24 familiar micropatterns over a pattern that contained a single familiar micropattern among 24 novel micropatterns. In other words, infants preferred to look at an array that had a single novel micropattern (and a majority of micropatterns that were familiar) over an array that had a single familiar micropattern (and a majority of micropatterns that were novel). Control groups revealed that infants prefer to look at novel stimuli under these conditions. These results indicated that infants' behavior was controlled by the unique discrepant element rather than the majority of elements surrounding this discrepant element in the visual arrays. Based on these results, Quinn and Bhatt (1998) concluded that the unique element that differed from the surrounding elements in terms of fundamental features must have attracted and engaged infants' attention (also see Bhatt, 1997; Bhatt et al., 1999; Rovee-Collier et al., 1992).

In the current study, we examined whether discrepancies in images that depict 3-D objects also engage infants' attention. If infants' attention is attracted and held by a discrepancy in a scene composed of 3-D polyhedral images but not by a comparable discrepancy in a scene composed of 2-D images, then this would be evidence that infants not only are sensitive to 3-D cues but that discrepancies based on these cues engage infants' attention.

One group of infants was habituated to a homogenous array of images that appeared to be 3-D blocks oriented in a particular direction and tested with one pattern containing a single block oriented in a novel direction among 15 familiar blocks paired with another pattern containing a single familiar block amidst 15 novel blocks (see Fig. 3). Another group was similarly habituated and tested with 2-D images (Fig. 3). If discrepancies in 3-D cues attract and engage infants' attention, then infants in the 3-D group should look more toward the pattern with the single novel element even though the majority of the elements in this pattern are familiar. In contrast, if the same discrepancy in 2-D images fails to attract and

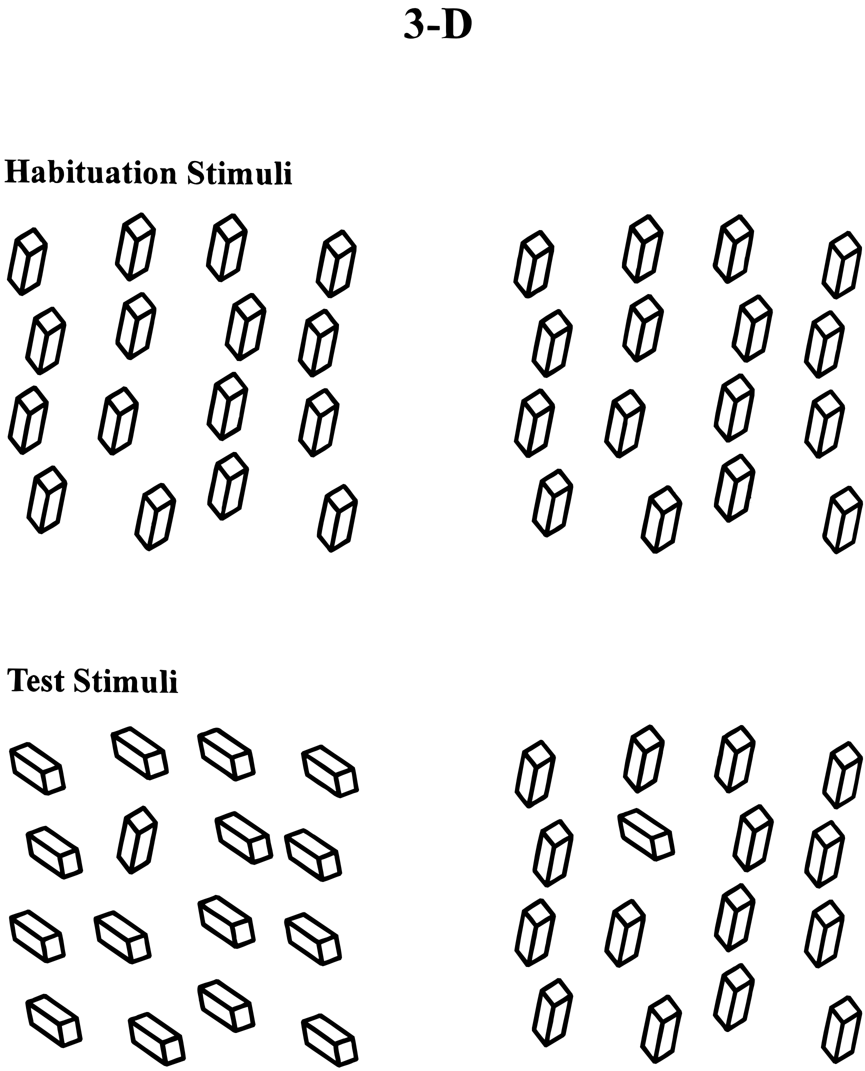
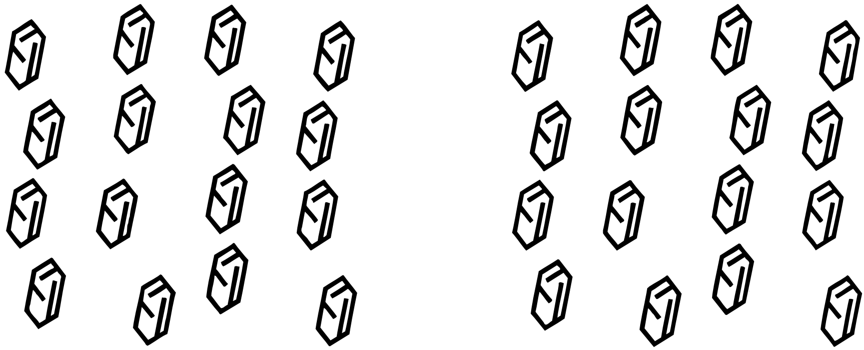


FIG. 3. Examples of the habituation and test patterns used in Experiment 2. Note that one of the test patterns is composed of a single familiar micropattern among novel micropatterns, while the other test pattern contains a single familiar micropattern among novel micropatterns. (Figure 3 is continued on next page.)

hold infants' attention, infants in the 2-D group should show the opposite kind of preference; i.e., they should look more toward the pattern with a majority of novel elements (if infants detect the overall orientation change of the 2-D images). This is because, as noted previously, Bhatt (1999) found that infants fail to detect individual misoriented micropatterns in 2-D arrays of the sort used in this experiment (Fig. 3). Thus, effectively, the two test patterns in the 2-D condition will be equiv-

2-D

Habituation Stimuli



Test Stimuli

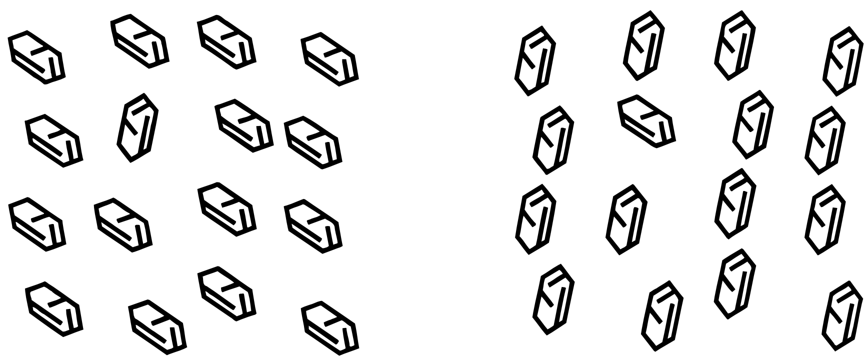


FIG. 3—*Continued*

alent to two homogeneous patterns, one identical to the study pattern and one with 15 micropatterns oriented in a novel direction. In this case, infants should prefer to look at the novel pattern.

Note that the test patterns are such that both of them had novel and familiar stimuli in both the 3-D and 2-D conditions (see Fig. 3). The question was whether the novelty induced by a single discrepant object would attract the infants' attention. If so, infants should prefer to look toward the pattern with the single novel object (even though the majority of the elements in this pattern were familiar and the majority of elements in the other pattern were novel). In other words, this procedure contrasts the novelty of a discrepant object against the novelty of the majority of elements in the arrays. Attentional engagement is inferred if the novelty of the discrepant element rather than the novelty of the majority of elements determines infants' behavior.

Bhatt and Waters (1998, Experiment 2) failed to find evidence of attentional engagement by discrepancies in images depicting 3-D information. They used a familiarization/novelty-preference procedure in which infants were familiarized to the homogeneous patterns for four 15-s trials and then tested for their preference between an array that contained a single novel element amidst familiar elements versus another array that contained a single familiar element amidst novel elements. In that study, infants failed to exhibit any kind of preference, that is, they exhibited a preference neither for the side with the single novel discrepant element nor for the side with a majority of novel elements. It is conceivable that the level of familiarization was not enough for infants to exhibit attentional engagement. We reasoned that the increase in looking times associated with the infant-control habituation procedure used in the current experiment would lead infants to exhibit appropriate preferences in the two conditions of the current study, that is, preference for the pattern with a single novel element amidst familiar elements in the 3-D condition and the opposite preference in the 2-D condition.

Method

Participants. Thirty-six full-term 3-month-olds (14 females, 22 males; mean age = 97.81 days; $SE = 1.34$ days) participated in this study. These infants were recruited in the same manner as those in Experiment 1. An additional 21 infants were excluded from this study for crying ($n = 13$) or for failing to sample both test stimuli ($n = 8$).

Stimuli. The stimuli were computer-generated versions of the 3-D and 2-D stimuli used by Bhatt (1999; see Figs. 1 and 3). The 3-D micropatterns were identical to the ones used in Experiment 1 of the current study. From the infants' viewpoint, each micropattern subtended roughly 2.86° of visual angle and each of the arrays subtended 17.06° $\times$ 17.06°. The test stimuli were a pattern containing a single discrepant novel micropattern surrounded by 15 familiar micropatterns paired with another containing a single familiar micropattern surrounded by 15 novel micropatterns (Fig. 3). Counterbalancing of the orientation of the habituation micropatterns, the position of the discrepant element, and the left–right position of the test patterns were carried out as in Experiment 1.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 1. That is, an infant-control procedure (Horowitz et al., 1972) was used to habituate infants to either 3-D or 2-D patterns oriented in a particular direction. One infant in the 3-D group and two infants in the 2-D group went through the complete 20 familiarization trials without meeting the habituation criterion. Their data are included in the final analysis. Immediately after the last habituation trial, infants were exposed to two 10-s test trials, during which infants were exposed to two patterns, one containing a novel micropattern amidst familiar micropatterns and the other containing a single familiar micropattern amidst novel micropatterns (Fig. 3).

As in Experiment 1, data coding of the test trial performance was conducted offline by an experimenter who was unaware of the left–right location of the test patterns. The performance of 12 randomly chosen participants was coded by another naïve experimenter to examine interobserver reliability. The average Pearson correlation between the two observers was 0.98 ($SE = 0.09$).

Results and Discussion

Table 2 displays the mean looking times during the first three and the last three habituation trials. A group (3-D, 2-D) × trial (first three, last three) ANOVA revealed a trial main effect, $F(1, 34) = 47.10$, $p < .001$. No other main or interaction effect was significant. Thus, while the infants exhibited a significant decline in looking times from the first three to the last three habituation trials (as required by the procedure), there was no evidence to suggest that the 2-D stimuli were treated any differently than the 3-D stimuli during the habituation phase of the experiment.

Table 2 also displays the preference scores exhibited by the two groups during the test. The preference score is the percentage of total looking toward the test patterns that was devoted to the pattern with the single novel element. Infants in the 3-D group looked more toward the pattern with the single novel micropattern (in spite of the 15 familiar micropatterns), whereas infants in the 2-D condition looked more toward the opposite pattern, i.e., the pattern with the majority of novel elements (Table 2 and Fig. 4). Preference for the pattern with the single novel element was significantly *greater* than the chance level of 50% in the 3-D condition, $t(17) = 2.44$, $p < .03$, whereas this preference was significantly *less* than the chance level of 50% in the 2-D condition, $t(17) = -2.26$, $p < .04$. Also,

TABLE 2
Mean (and Standard Error) of Fixation Duration during Familiarization Trials and Percentage of Preference for the Pattern with the Discrepant Novel Element during Test Trials in Experiment 2

	First three familiarization trials (seconds)	Last three familiarization trials (seconds)
3-D	38.54 (4.59)	16.22 (2.20)
2-D	42.77 (4.46)	19.87 (2.85)

Preference (%) for array single novel element during test trials

	M (*SE*)	*N*	*t* (vs chance)	*p* (two-tailed)
3-D	58.76 (3.58)*	18	2.44	<.03
2-D	42.48 (3.33)*	18	−2.26	<.04

Note. Asterisks indicate that the mean preference for the pattern with the individual novel element during the test was significantly different from the chance level of 50%.

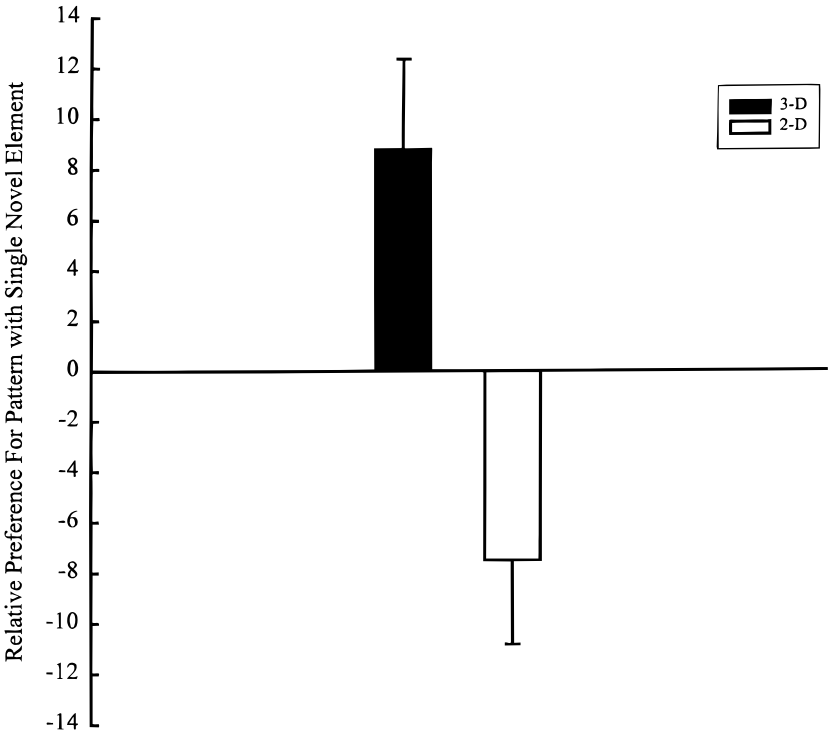


FIG. 4. Performance of the infants in the 3-D and 2-D conditions of Experiment 2. The relative preference score was computed by subtracting the chance level of 50% from the groups' preference scores (see Table 2). It indicates the relative preference for the side with the single novel micropattern among 15 familiar micropatterns versus the side with the single familiar micropattern among 15 novel micropatterns. A score that is greater than zero indicates a preference for the side with the single novel micropattern; a score that is less than zero indicates a preference for the opposite side.

there was a significant difference between the preference scores of the two groups, $t(34) = 3.33$, $p < .01$ (see Table 2 and Fig. 4).

Thus, infants' performance was determined by the single discrepant elements in the 3-D condition: Infants preferred the pattern with the single novel element to the pattern with the single familiar element. In contrast, performance was determined by the majority of elements of each pattern in the 2-D condition: Infants preferred the pattern with a majority of novel elements to the pattern with a majority of familiar elements. These results indicate that discrepancies in 3-D cues engage 3-month-olds' attention.

Note that the finding that discrepant individual elements determined infants' performance in the 3-D condition but not in the 2-D condition reinforces the conclusions arrived at by Bhatt and Waters (1998) and Bhatt (1999) that discrepancies based on 3-D cues in static images are discriminated by infants but comparable discrepancies in arrays of 2-D images are not. The fact that there is consistency in the results of these experiments despite the fact that there were stimulus and procedural changes across these studies strengthens the conclusion that 3-month-olds are sensitive to 3-D line junction cues.

While the results of both Experiments 1 and 2 suggest that infants failed to detect individual discrepant elements in 2-D arrays, the fact that infants in the 2-D condition of Experiment 2 exhibited a novelty preference for the array in which the majority of elements had a novel orientation suggests that, with sufficient numbers of novel elements, infants detect orientation changes in 2-D images also in patterns of the sort used in these experiments.

Another point to note concerns the fact that while Bhatt and Waters (1998, Experiment 2) failed to find evidence of attentional engagement by 3-D cues based on shading information, the current study indicates that 3-D cues derived from line junction information engage infants' attention. As noted above, a different procedure was used by Bhatt and Waters, a procedure in which infants were exposed to the homogenous patterns for only four 15-s familiarization trials, and infants exhibited no preference during the test. Thus, it is not possible to compare the performance of infants in these two studies, and it is conceivable that infants would exhibit an attentional engagement effect even with the stimuli used in Bhatt and Waters (1998) if an infant-control habituation procedure were used.

GENERAL DISCUSSION

The present study found that 3-month-old infants (a) are sensitive to combinations of line junction cues that signal 3-D structure and orientation information to adults and (b) exhibit attentional engagement by discrepancies in 3-D cues. These results indicate that 3-month-olds are not only sensitive to but also selectively attend to 3-D junction cues in static images that adults use to determine the structure and orientation of objects.

Bhatt and Waters (1998) had previously found that 3-month-old infants are sensitive to 3-D cues in static 2-D images. In that study, 3-month-olds detected a block that appeared to be illuminated from the bottom in an array of blocks that appeared to be illuminated from the top; however, they failed to detect comparable changes in control arrays with 2-D images. The stimuli in that study were composed of black/white patches and infants could have used shading information to derive 3-D cues. Note that in the current studies, line drawings were used as stimuli and no shading information was available. Thus, the current results go beyond the Bhatt and Waters (1998) findings by revealing that 3-month-olds are sensitive to 3-D cues available in line junctions themselves. That is, shading information is not necessary for 3-month-olds to exhibit sensitivity to 3-D cues.

In addition to demonstrating that 3-month-olds are sensitive to 3-D line junction cues, the current experiments add to the literature by demonstrating that young infants are sensitive to combinations of trilinear junctions (Experiment 1). Consistent with the PRISM model of 3-D information processing by adults (Enns, 1992; Enns & Rensink, 1991), infants appear to go beyond the processing of individual line junctions and appear to compute relations among these junctions. While understanding the exact precision and completeness of this structural processing by 3-month-olds requires further study, the results of Experiment 1 suggest that this processing proceeds to a stage that is minimally necessary for infants to discriminate a misoriented image in a pictorial array of 3-D objects.

This sensitivity to combinations of 3-D junction cues suggests that at least rudimentary aspects of the derivation of 3-D structural information from static images are available by 3 months of age. However, prior research suggests that the ability to derive complete 3-D form from pictorial cues does not develop until later in life, between 5 and 7 months of age (e.g., Kavsek, 1999; but see Caron et al., 1979; Slater & Morrison, 1985; for reviews, see Kellman, 1996; Kellman & Arterberry, 1998; Yonas et al., 1987). Logically, then, there are two possibilities: (a) 3-month-olds are unable to derive 3-D structure using pictorial cues although they exhibited sensitivity to these cues in the current experiments or (b) 3-month-olds are able to derive 3-D structure from pictorial cues, and the lack of evidence for that is based on limitations of the procedures and approaches used to study this issue. Although the history of developmental psychology is replete with examples of a previously established incompetence on the part of young infants being later shown to be a limitation of the procedures used to study the issue, prudence dictates that, in the absence of evidence to the contrary, it has to be assumed that the ability to derive 3-D structure from static cues does not develop until after 5 months of age. Given this assumption, further research is necessary to understand why 3-month-olds are unable to process complete 3-D structural and orientation information from pictorial cues although they are sensitive to the combinations of line junction cues that adults used to derive 3-D information.

Note that, in addition to the demonstration of sensitivity to pictorial 3-D cues, the current study indicated that infants' attention is engaged by discrepancies in 3-D line junction cues (Experiment 2). This result is significant for the following reason: Analogous to early research on adults, which found that only differences in fundamental features and not differences in combinations of features pop-out for adults, prior research suggested that only differences in fundamental features, such as line orientation, engage infants' attention (Bertin & Bhatt, 2001; Bhatt, 1997; Bhatt et al., 1999; Colombo, Ryther, Frick, & Gifford, 1995; Quinn & Bhatt, 1998; Rovee-Collier et al., 1992). In contrast, in the current study, differences in 3-D cues, which according to models of 3-D perception are based on trilinear junctions, also engaged infants' attention.

This result is thus analogous to the findings that adults exhibit pop-out of 3-D cues that are conjunctions of more primitive fundamental features of objects (Enns & Rensink, 1990, 1991; also see Ramachandran, 1988; Sun & Perona, 1996). Thus, in infancy, as in adulthood, the set of functional features that engage attention might be different from the set of simple features originally thought to be the building blocks of object perception (Treisman, 1988, 1993; Wolfe, 1998).

In the literature on adult perception, pop-out is operationally defined by the parallel processing of information and the measures typically used are latency to detect and/or percentage of correct detection of a discrepant element in an array (for reviews, see Treisman, 1993; Wolfe, 1998, 2000). Given that such measures were not used in the current study, it is impossible to tell whether infants also processed information in parallel. Therefore, while it is clear from the results of Experiment 2 that discrepancies in 3-D cues engage 3-month-olds' attention, it is not clear whether this involved the parallel processing of information. Nevertheless, the fact that stimulus attributes that pop-out for adults also engage the attention of infants (3-D cues) while those that do not pop-out for adults do not engage the attention of infants (comparable 2-D cues; also see Bertin & Bhatt, 2001; Bhatt, 1997; Quinn & Bhatt, 1998) suggests that similar mechanisms of 3-D featural processing might be involved in infancy and adulthood.

Also, the finding that infants selectively attend to 3-D line junction cues is consistent with a number of models of object perception that assume that edges and junctions are critical for object recognition (e.g., Biederman, 1987; Hoffman & Richards, 1984). The results of the current experiments suggest that at least rudimentary aspects of the mechanisms that are involved in deriving 3-D structural information from edges and junctions in static images are available by 3 months of age.

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REPORT

The Thatcher illusion and face processing in infancy

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Abstract

Adults readily detect changes in face patterns brought about by the inversion of eyes and mouth when the faces are viewed upright but not when they are viewed upside down. Research suggests that this illusion (the Thatcher illusion) is caused by the interfering effects of face inversion on the processing of second-order relational information (fine spatial information such as the distance between the eyes). In the current study, 6-month-olds discriminated 'thatcherized' faces when they were viewed upright but not when they were viewed upside down. These results are consistent with the notion that 6-month-olds are sensitive to second-order relational information while processing faces.

Introduction

From a very early age, humans possess a remarkable ability to discriminate and remember faces (e.g. Pascalis, deHaan, Nelson & de Schonen, 1998; Rhodes, Geddes, Jeffery, Dziurawiec & Clark, 2002; Slater, Quinn, Hayes & Brown, 2000). Faces afford several types of information upon which discrimination and memorization can be based. For example, we might discriminate or remember a face on the basis of a salient facial feature, such as a big nose (*featural information*), or on the basis of the spatial arrangement among the features, such as the spatial relationship between the nose and the mouth (*configural information*). Although agreed-upon terminology and definitions of featural and especially configural information remain elusive (e.g. compare the definition of configural information by Tanaka and Farah (1993) versus Diamond and Carey (1986)), generally speaking, the former refers to individual facial components such as the nose, mouth and eye, and the latter to the arrangement and spatial relationships among these features. Research has revealed that both kinds of information are important in face recognition (e.g. Carey & Diamond, 1977; Cabeza & Kato, 2000; Deruelle & de Schonen, 1998; Diamond & Carey, 1986; Hay & Cox, 2000; Freire & Lee, 2001; Freire, Lee & Symons, 2000; Leder & Bruce, 2000; Maurer, Le Grand & Mondloch, 2002; Searcy & Bartlett, 1996; Sergent, 1984).

Diamond and Carey (1986) proposed a definition of configural information that sub-divides this type of relational information into *first-order* and *second-order* relational information. In terms of faces, first-order relational information refers to the gross, qualitative spatial relations among facial features (e.g. the nose is located above the mouth). Second-order relational information refers to the fine spatial relations among features (e.g. the metric distance between the nose and the mouth relative to prototypical face arrangement). Because all faces share the same first-order relational information (e.g. the nose is *always* located above the mouth), subtle spatial second-order information might become crucial to individuate faces. Research generally supports the scheme proposed by Diamond and Carey: Adults utilize both first-order and second-order relational information to process faces (e.g. Barton, Keenan & Bass, 2001; Maurer *et al.*, 2002; Murray, Yong & Rhodes, 2000; Freire *et al.*, 2000).

Several researchers have investigated the development of the use of relational information to process faces (e.g. Cohen & Cashon, 2001; Deruelle & de Schonen, 1998; Le Grand, Mondloch, Maurer & Brent, 2001; Rose, Jankowski & Feldman, 2002). There is, for instance, a considerable amount of research indicating that even newborns are sensitive to first-order information – as inferred from their ability to discriminate between schematic faces with normally configured versus scrambled features (e.g. Easterbrook, Kisilevsky, Muir & Laplante, 1999; Johnson, Dziurawiec, Ellis & Morton, 1991; Johnson & Morton, 1991; Mondloch, *et al.*, 1999; Valenza, Simion, Cassia & Umiltà, 1996). While the use of first-order

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information to process faces early in life is well established, it is not clear whether children and infants use second-order information (e.g. Carey & Diamond, 1977, 1994; Cohen & Cashon, 2001; Freire & Lee, 2001; Hay & Cox, 2000; Maurer *et al.*, 2002; Schwarzer, 2000; Tanaka, Kay, Grinnell, Stansfield & Szechter, 1998). Some studies indicate that adult-like sensitivity to second-order relational information might not be reached until about 10 years of age or even later (e.g. Carey & Diamond, 1994; Mondloch, Le Grand & Maurer, 2002). If older children rely less on second-order relational information to process faces than adults, then it is possible that infants are not even sensitive to this kind of information.

A study by Thompson, Madrid, Westbrook and Johnston (2001) provides some evidence that 7-month-olds are able to discriminate faces on the basis of second-order relational information. In this study, two types of faces that differed only in the spacing of the internal features (i.e. eye-to-mouth and eye-to-chin distance) were presented to infants. Infants exhibited a visual preference for the face that conformed to average distance measurements, which is consistent with the conclusion that infants are able to discriminate the second-order relational information that differentiated the two kinds of face stimuli.

The present study was designed to provide convergent evidence for infants' sensitivity to second-order relational information. To this end, we examined whether 6-month-olds experience the Thatcher illusion (Thompson, 1980). This illusion is experienced by adults who are exposed to a face in which the eyes and the mouth are inverted on an otherwise upright face (a 'thatcherized' face). Thatcherization bestows a grotesque expression on the face that is readily noticed by adults when the image is viewed upright. If, however, the entire thatcherized image is rotated 180°, the bizarre expression gives way to a more neutral appearance, which adults only detect with difficulty (e.g. Bartlett & Searcy, 1993; Lewis & Johnston, 1997; Murray *et al.*, 2000; Stürzel & Spillmann, 2000; Thompson, 1980).

Some researchers have claimed that thatcherizing a facial pattern changes second-order relational information *without* altering featural and first-order relational information, and have argued that, therefore, this illusion (i.e. the failure to quickly discriminate a thatcherized face from an unaltered face when viewed upside down) is caused by the disruption of second-order relational information processing (e.g. Bartlett & Searcy, 1993; Murray *et al.*, 2000; but see Cabeza & Kato, 2000; Leder & Bruce, 2000; Maurer *et al.*, 2002; Tanaka & Farah, 1991).

In the current study, we examined whether 6-month-olds experience the Thatcher illusion. If, like adults, infants detect thatcherization changes when face patterns are viewed upright but not when they are viewed upside down, then this would be evidence consistent with the notion that infants are also sensitive to second-order relational information, thereby providing convergent evidence for the conclusion arrived at by Thompson *et al.* (2001).

We employed a habituation–novelty preference procedure in which infants are familiarized to a stimulus and then tested for their ability to discriminate a stimulus change by pairing the familiar stimulus with a novel stimulus. Visual preference for the novel stimulus is indicative of successful discrimination.

Method

Participants

Thirty-two full-term 6-month-old infants (15 females, 17 males; mean age = 182.41 days, SD = 9.172) participated in this study. They were recruited from public birth announcements and were predominantly Caucasians from middle-class backgrounds. An additional 11 participants were excluded from the study for fussiness ($n = 8$) and for failure to sample both test stimuli ($n = 3$).

Stimuli

The stimuli consisted of two colorful clipart face patterns depicting a female face. One was a normal, unaltered portrait (Figure 1, panels A and C). The other was the thatcherized face (Figure 1, panels B and D) created by inverting the eyes and mouth of this portrait. The stimuli were printed on white cardboard. From the infant's viewpoint, the face pattern subtended 23.16° horizontally and 27.63° vertically. Infants in the *Upright* condition were habituated and tested with upright stimuli (Figure 1, panels A and B), while those in the *Inverted* condition were habituated and tested with the same stimuli presented upside down (Figure 1, panels C and D). Also, the stimuli were counterbalanced across participants, such that the normal and thatcherized patterns were equally often the habituation and novel test pattern within each condition.

Apparatus

The portable apparatus used was a modified version of the apparatus used by Fagan (1970; Bertin & Bhatt, 2001; Bhatt & Waters, 1998). It consisted of a hinged, three-sided stage that contained two compartments to hold stimulus cards. A 60 W fluorescent bulb, hidden from the infant's view by an overhanging shelf, illuminated the stage. The infant was exposed to the stimulus

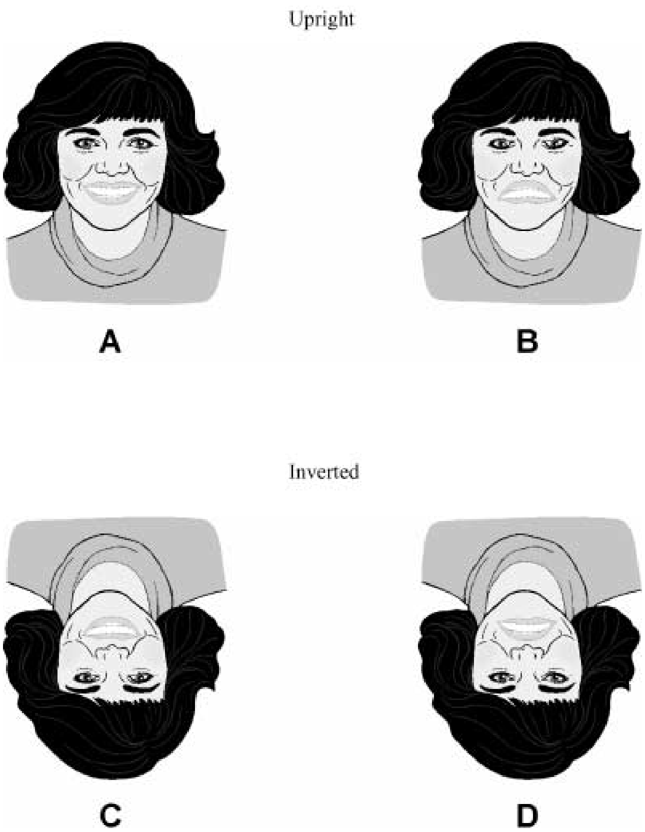

Figure 1 *Infants in the* Upright *condition were habituated to an unaltered face (panel A) or a thatcherized face (panel B) before being tested for discrimination between the two kinds of faces (panel A versus panel B). Infants in the* Inverted *condition were habituated and tested with the same stimuli, except that the faces were presented upside down during both habituation and test trials (panels A and C). The actual face patterns shown to infants were in color.*

cards placed in the display compartments (center to center distance = 30.50 cm) when the stage was closed. The infant was exposed to the experimenter and could not see the stimulus cards when the stage was open. Participants were seated about 30.50 cm in front of the display panel (closed stage) in an infant seat that was inclined at 45° to correspond to the angle of the stage. A 0.625 cm peephole in the middle of the display screen allowed the recording of infants' look direction using a Pro Video CVC-120PH pinhole camera and a Sony GV-A500 portable video recorder. The whole apparatus was painted black.

Procedure

Experimental sessions were conducted in the infants' home at a time when they were likely to be alert as indicated by their parents. The sessions began with the portable apparatus being wheeled over the infant who was seated in an infant seat, keeping the infant's head centered with respect to the midline of the display stage. An infant-control habituation procedure was used in this study (e.g. Bertin & Bhatt, 2001; Horowitz, Paden, Bhana & Self, 1972). Each habituation and test trial began with the display stage open and the experimenter attracting the infant's attention to the middle of the display stage. Once attention was secured, the stage was closed to display two face patterns to the infant, one on the left and the other on the right. The camera and VCR recorded the direction of the infant's gaze.

During a typical habituation trial, infants were simultaneously exposed to two identical copies of the habituation face pattern until they looked away for 2 consecutive seconds or until a maximum of 60 s had elapsed. (During test trials, one of the patterns was replaced by a novel face – see below.) Habituation trials were repeated until the mean look duration during three consecutive trials for each infant was less than or equal to half of the mean look duration during the first three trials for the same infant or until the infant had gone through a maximum of 20 habituation trials. This way, the habituation criterion was determined for each infant individually. All infants met their individually determined habituation criterion within 20 trials (*Upright:* Mean = 7.25 habituation trials, SD = 3.00; *Inverted:* Mean = 6.88 habituation trials, SD = 1.75). Immediately after the last habituation trial, infants were exposed to two 10-s test trials during which a habituation face pattern was paired with a novel face pattern. The left-right positioning of the novel face pattern on the first test trial was counterbalanced across participants in each group; the position of this novel face pattern was reversed on the second test trial.

The habituation and test stimuli were counterbalanced within each condition, so that the normal and the thatcherized face served equally often as the habituation and novel test stimulus. That is, half of the infants in the *Upright* orientation condition were habituated to the normal face presented upright (Figure 1, panel A) while the other half of the infants were habituated to the thatcherized face pattern presented upright (Figure 1, panel B). Similarly, half of the infants in the *Inverted* orientation condition were habituated to an inverted normal face (Figure 1, panel C) and the other half of the infants were habituated to an inverted thatcherized face (Figure 1, panel D). During the discrimination test, infants in both orientation conditions were tested for their preference between a familiar (normal or thatcherized) face and a novel face (thatcherized or normal) presented in the same orientation as during habituation (Figure 1). Note that there was no change in orientation from habituation to test within each condition.

Table 1 *Mean (and standard error) of fixation duration during habituation trials and percentage of preference for the novel face pattern during test trials*

	First three habituation trials (seconds)		Last three habituation trials (seconds)	
Upright ($n = 16$)	27.76 (3.15)		10.59 (1.88)	
Habituation to normal face (n = 8)	28.53 (4.77)		13.64 (2.65)	
Habituation to thatcherized face (n = 8)	26.98 (4.40)		7.54 (2.32)	
Inverted ($n = 16$)	23.24 (4.14)		8.34 (1.61)	
Habituation to normal face (n = 8)	27.56 (7.04)		8.89 (2.29)	
Habituation to thatcherized face (n = 8)	18.93 (4.33)		7.78 (2.39)	
Preference (%) for novel face pattern during test trials				
	M (SE)	*N*	*t(vs. chance)*	*p(two-tailed)*
Upright	60.17 (3.77)*	16	2.70	<.02
Habituation to normal face	58.94 (5.05)	8	1.77	>.05
Habituation to thatcherized face	61.40 (5.91)	8	1.93	>.05
Inverted	47.35 (4.08)	16	−0.65	>.05
Habituation to normal face	52.64 (5.05)	8	0.47	>.05
Habituation to thatcherized face	42.05 (5.59)	8	−1.42	>.05

Note: Asterisks indicate a mean novelty preference score that is significantly greater than the chance level of 50%. Half of the infants in each condition were familiarized with the normal face and the other half with the thatcherized face as a counterbalancing measure. Their data are shown separately above.

Infants' looking times during the test trials were coded from video records by an observer that was blind to the position of the novel face pattern. The videotape was reduced to 20% of normal speed for coding. Another naïve experimenter coded the performance of nine infants. The average Pearson correlation coefficient between the two scorers in terms of looking times to the right and to the left was 0.98.

Results

Preliminary analyses revealed that the infants' gender did not significantly affect their performance during the habituation and test trials. Thus, the data were collapsed over this variable in subsequent analyses. Table 1 displays the mean looking times during the first three and the last three habituation trials. An orientation (upright, inverted) × face type (normal, thatcherized) × trial (first three, last three) ANOVA revealed only a trial main effect, $F(1, 28) = 74.39$, $p < .001$. No other main or interaction effect was significant (orientation: $F(1, 28) = 0.86$, $p > .05$; face type: $F(1, 28) = 1.42$, $p > .05$; orientation × trial: $F(1, 28) = 0.37$, $p > .05$; orientation × face type: $F(1, 28) = .021$, $p > .05$; face type × trial: $F(1, 28) = 0.16$, $p > .05$; orientation × face type × trial: $F(1, 28) = 2.64$, $p > .05$). Thus, while the infants exhibited a significant decline in looking times from the first three to the last three habituation trials (as required by the procedure), neither the orientation of the face (upright versus inverted) nor its type (normal versus thatcherized) significantly affected habituation patterns.

Table 1 also displays the novelty preference scores exhibited by the two groups during the test. This score was computed by dividing the duration of looking toward the novel face pattern during the two test trials by the total duration of looking toward both face patterns during the test and by multiplying this proportion by 100 to get a percentage novelty preference score. A mean novelty score greater than 50% indicated that the infants preferred to look at the novel face pattern. The infants' ability to discriminate the changes between the original and the thatcherized face pattern was inferred from such preferential looking. In contrast, a mean novelty score that was not different from 50% was assumed to indicate that infants failed to exhibit evidence of discrimination between the original and the thatcherized face pattern.

As can be seen in Table 1, infants in the *Upright* condition discriminated the thatcherization change during the test, whereas infants in the *Inverted* condition did not. Infants in the *Upright* condition exhibited a novelty preference score that was significantly greater than the chance level of 50%, $t(15) = 2.70$, $p < .02$, two-tailed, whereas infants in the *Inverted* condition failed to do so, $t(15) = -0.65$, $p > .05$, two-tailed. Moreover, an orientation (upright, inverted) × face type (normal, thatcherized) ANOVA revealed only a significant effect of orientation, $F(1, 28) = 5.35$, $p < .05$, indicating that the novelty preference score of the *Upright* group was significantly greater than the novelty preference score of the *Inverted* group. Neither the face type, $F(1, 28) = 0.54$, $p > .05$, nor the orientation × face type interaction, $F(1, 28) = 1.38$, $p > .05$, was significant. This suggests that it did not matter whether the infants were habituated to normal faces and tested with the thatcherized face or vice versa. What mattered was the orientation of the face stimuli: When the faces were viewed upright, infants detected the thatcherization changes; when the faces were inverted, infants failed to detect the same changes.

Discussion

In the present study, infants discriminated the changes between an unaltered and a thatcherized face when the faces were presented upright, but failed to discriminate the same changes when the faces were presented upside down. Thus, as in the case of adults, 6-month-olds' discrimination of thatcherized faces was disrupted by inversion.

As noted previously, some researchers have suggested that the only differences between an unaltered and a 'thatcherized' face are changes in second-order relational information (i.e. without changes in featural and first-order relational information; see Bartlett & Searcy, 1993; Murray *et al.*, 2000). Based on this, it could be argued that the current results indicate that 6-month-olds are sensitive to second-order relational information. However, research also suggests that facial inversion affects not only second-order information but also first-order and featural information (e.g. Cabeza & Kato, 2000; Collishaw & Hole, 2000; Leder & Bruce, 2000; Maurer *et al.*, 2002; Purcell & Stewart, 1988; Tanaka & Farah, 1991). The current study did not directly assess the relative impacts of featural, first-order and second-order information in the Thatcher illusion effect exhibited by infants. Therefore, given the absence of a direct test, the current results can only be characterized as being consistent with the notion that infants are sensitive to second-order relational information and cannot be viewed as directly proving such sensitivity.

The results obtained are also consistent with findings of previous face processing research with infants. For example, Thompson *et al.* (2001) provided evidence that 7-month-olds were sensitive to second-order relational information afforded by upright faces. The present study found that for infants, as for adults (e.g. Lewis & Johnston, 1997; Murray *et al.*, 2000), inversion disrupts the processing of thatcherized faces. Thus, using a different procedure and slightly younger infants, the present study provides convergence evidence consistent with the conclusion by Thompson *et al.* (2001) that young infants may be sensitive to second-order relational information while processing faces.

Needless to say, many questions remain unanswered. For instance, adults experience thatcherized faces to be grotesque or bizarre (Thompson, 1980). It is unclear whether infants also experience thatcherized faces in the same way. Further research is necessary to answer this question. More generally, further research is necessary to understand the interplay between featural, first-order and second-order information in face processing and the manner in which the use of different kinds of information develops from birth.

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Face Processing in Infancy: Developmental Changes in the Use of Different Kinds of Relational Information

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Adults use both first-order, or categorical, relations among features (e.g., the nose is above the mouth), and second-order, or fine spatial relations (e.g., the space between eyes), to process faces. Adults' expertise in face processing is thought to be based on the use of second-order relations. In the current study, 5-month-olds detected second-order changes, but 3-month-olds failed to detect second-order changes induced by 2 different manipulations. Three-month-olds did detect first-order changes, however. Also, inversion affected 5-month-olds' processing of second-order but not first-order information. These results suggest that, although sensitivity to first-order relations is available by 3 months or earlier, sensitivity to second-order information may not develop until sometime between 3 and 5 months of age.

From the beginning of the modern era of research on infant cognitive development (e.g., Fantz, 1961), there has been considerable interest in infants' face processing (for recent reviews, see Gauthier & Nelson, 2001; Pascalis & Slater, 2003). There is evidence that even newborns might be able to process faces or at least face-like configurations (e.g., Bushnell, 2003; Field, Cohen, Garcia, & Greenberg, 1984; Johnson, Dziurawiec, Ellis, & Morton, 1991; Johnson & Morton, 1991; Mondloch et al., 1999; Pascalis, de Schonen, Morton, Deruelle, & Rabre-Grenet, 1995; Quinn & Slater, 2003; Simion, Cassia, Turati, & Valenza, 2003; Valenza, Simion, Cassia, & Umilta, 1996). One issue that has received great attention is the question of whether faces are perceived as a collection of disparate features or as cohesive, holistic images that incorporate the spatial relations among features (e.g., Cashon & Cohen, 2003; Deruelle & de Schonen, 1998; Maurer & Berrera, 1981; Maurer, Le Grand, & Mondloch, 2002). However, research suggests that different kinds of spatial relations might be involved in face processing by adults (e.g., Maurer et al., 2002; Tanaka & Farah, 2003), but not much is known about the development of sensitivity to these kinds of relational information in infancy (Cashon & Cohen, 2003). The current research examined the development of sensitivity to two different kinds of relations—first- and second-order spatial relations—that adults use to process faces.

Diamond and Carey (1986) posited that three kinds of information are involved in face processing: featural, first-order relations, and second-order relations. Featural information pertains to facial parts or discrete components, such as eyes and nose. First-order relations involve the categorical spatial relations among these components, such as the fact that the eyes are located above the nose. Second-order relations specify the fine spatial information among these features, such as the distance between the eyes, in reference to a prototypical face. The model proposed by Diamond and Carey assumes a significant role for second-order information because all faces share the same first-order configuration. In other words, according to the Diamond and Carey model, all faces are composed of the same qualitative spatial relations among their components; therefore, faces differ based on variations in features and second-order relations, and it is necessary to process both of these kinds of information to discriminate among different faces at a fully functional level.

Some reports seem to suggest that even newborns may be sensitive to overall facial configurations (i.e., first-order relations in the Diamond & Carey, 1986, system; e.g., Fantz, 1961; Mondloch et al., 1999;

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Simion et al., 2003), whereas other reports suggest that it may be 2 to 4 months of age before infants become sensitive to such information (e.g., Acerra, Burnod, de Schonen, 2002; Haaf, 1974; Maurer & Barrera, 1981). In any case, it is safe to say that infants are sensitive to first-order relational information within the first few months of life. There is no comparable information available, however, about the development of sensitivity to second-order relational information during the first 6 months of life. The current research examined the development of sensitivity to first- and second-order spatial relations from 3 to 5 months of age.

It is important to examine the development of sensitivity to second-order information because it has been suggested that adults' expertise at processing faces derives from their ability to encode and use second-order relational information (Carey & Diamond, 1994; Diamond & Carey, 1986). According to Carey and Diamond (1994), expertise derives from the knowledge of a configural prototype against which other objects within that category are compared to compute second-order information. This second-order information allows the expert in that domain to discriminate rapidly and accurately among the exemplars of that category. Furthermore, faces are the only class of stimuli with which most adults have sufficient expertise to allow the use of second-order information (Carey & Diamond, 1994; Tanaka & Farah, 2003). Thus, a comprehensive understanding of how adults become experts at processing faces requires examination of the development of the ability to process second-order relational information from early in life.

The importance of the study of second-order relational processing in early infancy also arises from the fact that there is research suggesting that adult-like sensitivity to second-order information may not be available until 10 or even 14 years of age (Carey & Diamond, 1994; Freire & Lee, 2001, 2003; Mondloch, Le Grand, & Maurer, 2002, 2003; Schwarzer, 2000; but see Itiera & Taylor, 2004; Want, Pascalis, Coleman, & Blades, 2003). Moreover, Mondloch et al. (2003) found that the absence of visual input in early infancy affects the development of sensitivity to second-order, but not first-order, relational information. Thus, second-order information processing might be a qualitatively different kind of relational processing that is a significant component of face processing, whose development is based on experience in early infancy, and that may not be completely developed well into childhood. It is therefore important to examine the development of sensitivity to this kind of information in early infancy.

To our knowledge, only three studies have examined the role of second-order relational information in face processing in infancy, and all of them have involved infants that are 6 months or older. Thompson, Madrid, Westbrook, and Johnston (2001) exposed infants to two types of face patterns: "normal" (unaltered) faces and distorted faces in which the spacing between the eyes and between the nose and the mouth were increased or decreased. Infants preferred normal faces over distorted faces. That is, infants preferred the faces in which the second-order spatial relations were closer to prototypical values, thus indicating that 7-month-olds are sensitive to second-order information. Rose, Jankowski, and Feldman (2002) concluded that 7- and 12-month-olds are sensitive to second-order information because their performance in a face discrimination task was affected by the fracturing of the images of faces in such a manner that first-order relations were left intact but second-order relations were disrupted. Bertin and Bhatt (2004) found that 6-month-olds exhibit a phenomenon analogous to the Thatcher illusion in adults (Thompson, 1980) in that they discriminated a *thatcherized* face when the face stimuli were presented upright but not when they were inverted. Thatcherization involves the inversion of the eye and the mouth regions of a facial image. To adults, thatcherized faces look grotesque when viewed upright but not when viewed upside down. Several researchers have argued that the Thatcher illusion is a result of the interfering effects of inversion on the processing of second-order information (Bartlett & Searcy, 1993; Freire, Lee, & Symons, 2000; Murray, Rhodes, & Schuchinsky, 2003; Murray, Yong, & Rhodes, 2000; Thompson, 1980). Thus, the Bertin and Bhatt results suggest that 6-month-olds are sensitive to second-order information.

The current studies differed from these prior studies in several ways. First, we examined the development of sensitivity to second-order information during the first 5 months of life. Second, we contrasted the development of sensitivity to first-order versus second-order information during this period. Third, we examined whether in infancy, as in adulthood, inversion affects the processing of second-order relations more than the processing of first-order relations.

Experiment 1

In this experiment we examined whether 3-month-olds exhibit a Thatcher illusion effect similar to the one exhibited by 6-month-olds in Bertin and Bhatt (2004) and by adults (Thompson, 1980). Many researchers have argued that the Thatcher illusion is a result of the interfering effects of inversion on the processing of second-order relational information (e.g., Bartlett & Searcy, 1993; Freire et al., 2000; Murray et al., 2003; Murray et al., 2000). However, the link between the Thatcher illusion and second-order processing is not necessarily direct (Maurer et al., 2002) and has not been explored in relation to infants' face processing. Nevertheless, given the predominance of evidence linking the Thatcher illusion to second-order processing in the adult literature, we reasoned that if 3-month-old infants also exhibit a phenomenon analogous to the Thatcher illusion effect exhibited by adults, it would be evidence consistent with the notion that they are sensitive to second-order relational information.

In the Bertin and Bhatt (2004) study, 6-month-olds discriminated between an unaltered face and a face in which the eyes and mouth regions were inverted when these face patterns were presented upright but not when they were presented upside down (see Figure 1). In the current experiment, we used the same stimuli and the same procedure to examine whether 3-month-olds exhibit a similar Thatcher illusion.

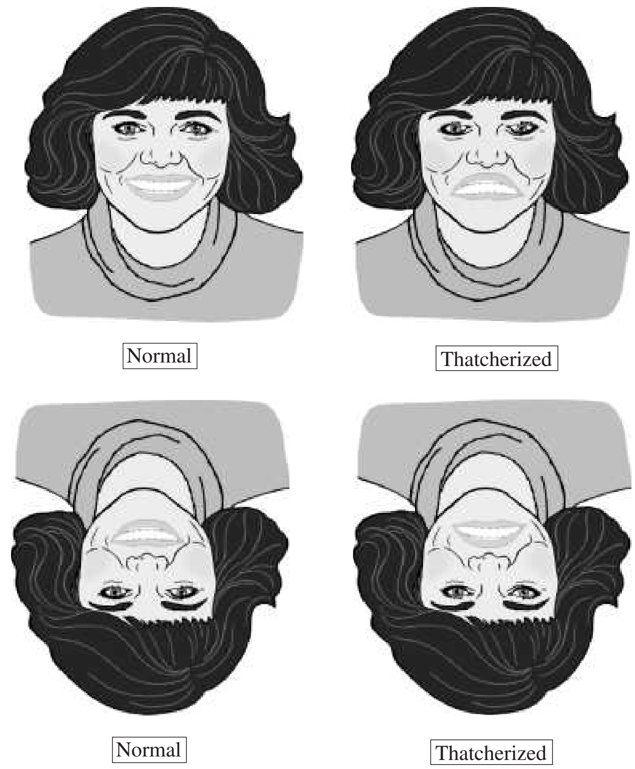

Figure 1. The stimuli used in Experiment 1. Infants in the upright condition were habituated and tested with upright faces (top panel). Infants in the inverted condition were habituated and tested with the same stimuli except that the faces were presented upside down during both habituation and test trials (bottom panel). The actual face patterns shown to infants were in color.

Method

Participants. Twenty-eight 3-month-olds (M age = 101.25 days, $SD = 7.05$; 13 females, 15 males) participated in this study. They were recruited using birth announcements in local newspapers and by word of mouth. These infants were predominantly White and from middle-class families. An additional 15 were recruited but were not included in the study because of fussiness ($n = 11$), falling asleep ($n = 2$), or failure to sample both test stimuli (i.e., position preference) during the test ($n = 2$).

Stimuli. The stimuli were colored images of a female face that were used in Bertin and Bhatt (2004). The normal face was the unaltered version, and the thatcherized face was this normal face with the eye and mouth regions inverted (Figure 1). From the infants' viewpoint, the face pattern subtended 23.16° horizontally and 27.63° vertically. In the upright condition, infants were habituated and tested with upright stimuli (Figure 1, top panel). In the inverted condition, infants were habituated and tested with inverted stimuli. (Figure 1, bottom panel).

Apparatus and procedure. The apparatus and procedure used in this experiment were the same as those used by Bertin and Bhatt (2004; see also Bertin & Bhatt, 2001; Bhatt & Waters, 1998). Infants were tested using a visual preference apparatus, adapted from Fagan (1970), which contained a hinged stage with two compartments to hold stimulus cards. A 60-watt fluorescent bulb, shaded from the infant's view by an overhanging shelf, illuminated the stage. Infants were exposed to the stimulus cards in the two compartments when the stage was closed; they were exposed to the experimenter when it was open. The infants were seated about 30.5 cm in front of the display stage in an infant seat that was inclined at 45° to correspond to the angle of the closed stage. Infants' look durations and directions were recorded using a Pro Video CVC-120PH pinhole camera via a 0.625 cm peephole in the middle of the display screen. A Sony GV-A500 portable video recorder allowed the monitoring of the infants' looks during the test session, and an IBM portable computer was used to program the test sessions.

Infants were tested at their homes at a time when their parents indicated they were likely to be alert. During the test sessions, the infants, seated in an infant seat, were located such that they were centered with respect to the midline of the display stage.

Each habituation and test trial began with the stage open and the experimenter drawing the infant's attention to the middle of the stage. Once the infant looked toward the experimenter, the stage was closed, and the trial began. At this point, the infant could see only the stimuli and the black surroundings of the test apparatus. At the end of each trial, the experimenter opened the display stage, recentered the gaze of the infant, and started the next trial.

As in Bertin and Bhatt (2004), an infant control procedure was used in this experiment (Horowitz, Paden, Bhana, & Self, 1972). Each habituation trial lasted until the infant looked away for 2 s or until 60 s had elapsed. Habituation trials were repeated until the mean looking time during 3 consecutive trials was less than half of the mean looking time during the first 3 trials or until a maximum of 20 trials had been reached. Two 10-s test trials followed immediately after the last habituation trial.

As noted earlier, infants in the upright condition were habituated and tested with upright stimuli (Figure 1, top panel), whereas those in the inverted condition were habituated and tested with inverted stimuli (Figure 1, bottom panel). During habituation, half of the infants in each condition were exposed to two identical exemplars of the normal face, and the other half was exposed to the thatcherized face. During the test trials, infants were tested for their preference between the habituation face and the other face. The left–right positioning of the novel face was counterbalanced across participants during the first test trial; its position was switched during the second test trial.

During habituation trials, the experimenter used the display attached to the VCR and the computer to record infants' looks toward or away from the habituation stimuli. A Macromedia Authorware computer program used this information to determine the duration and number of habituation trials. Infants' look directions during the test trials were coded offline by a trained observer who was unaware of the location of novel pattern on each trial. The speed of the video display was reduced to 20% of normal speed for scoring purposes. The performance of 9 randomly chosen participants was coded by another naive experimenter to examine interobserver reliability. The average Pearson correlation between the two observers was 0.98 ($SE = .01$).

Results and Discussion

Table 1 displays the mean looking times during the first three and last three habituation trials. A Group (upright, inverted) × Familiarization Stimulus (normal, thatcherized) × Trial (first three, last three) analysis of variance (ANOVA) revealed a trial main effect, $F(1, 24) = 174.82$, $p < .001$; a group main effect, $F(1, 24) = 8.84$, $p < .01$; and a Group × Trial interaction, $F(1, 24) = 6.64$, $p < .05$. Follow-up least significant difference pairwise comparisons indicated that infants in the upright condition looked longer at the habituation patterns during both the initial three and the last three test trials than did infants in the inverted condition. Thus, the 3-month-olds in this study preferred upright facial configurations to inverted facial configurations. As required by the infant control habituation procedure, however, infants in both groups were habituated to the same criterion before being tested (50% decline in average look duration in three consecutive trials), and this is reflected in the significant trial main effect. The nature of the familiarization stimulus (i.e., whether it was the normal face or the thatcherized face) did not affect familiarization: The main effect of familiarization stimulus was not significant, and it did not interact with other factors, all $ps > .20$.

The preference scores exhibited by the two groups during the test trials are displayed in Table 1. The preference score is the percentage of total looking time toward the two test patterns that was devoted to the novel test pattern. In this and the following experiments, a mean novelty preference score that is greater than 50% was taken to indicate that the infants in that group had discriminated the differences in the face pattern between the thatcherized versus normal face patterns. In contrast, a mean novelty preference score that was not greater than 50% was taken to indicate that the infants had failed to discriminate the differences between the thatcherized and normal face pattern. As can be seen in Table 1,

Table 1
Mean (and Standard Error) of Fixation Duration During Habituation Trials and Percentage Novelty Preference Exhibited During Test Trials in Experiment 1

	First three familiarization trials (s)	Last three familiarization trials (s)
Upright	45.26 (3.48)	15.90 (1.94)
Inverted	28.65 (4.49)	8.87 (1.65)

	Preference (%) for novel pattern during test trials			
	M (SE)	N	t (vs. chance)	p (two-tailed)
Upright	47.96 (4.40)	14	– 0.46	> .05
Inverted	46.31 (5.92)	14	– 0.62	> .05

neither group exhibited a novelty preference score that was higher than 50%, $t(13) < 1$. A Group (upright, inverted) $\times$ Familiarization Stimulus (normal, thatcherized) ANOVA revealed no significant main or interaction effects, all $ps > .30$. Thus, neither the orientation of the familiar and test stimuli (upright or inverted) nor the nature of the familiarization pattern (normal or thatcherized) had a significant effect on performance.

The 3-month-olds in this study did not discriminate thatcherization changes in either upright or inverted face images. In contrast, 6-month-old infants in the Bertin and Bhatt (2004) study detected a thatcherized face when tested with upright images but not when tested with inverted images. Thus, 3-month-olds failed to demonstrate sensitivity to second-order information as measured by the Thatcher illusion, whereas 6-month-olds in Bertin and Bhatt did. These data suggest a developmental change in sensitivity to second-order relations.

However, as noted previously, although many researchers have directly linked the Thatcher illusion with second-order processing (Bartlett & Searcy, 1993; Freire et al., 2000; Murray et al., 2003; Murray et al., 2000), some researchers have not (e.g., Maurer et al., 2002). It remains an open question, therefore, whether 3-month-olds' failure to discriminate thatcherized faces in Experiment 1 is evidence of a failure to process second-order information. In the next experiment, we sought to examine directly infants' ability to process second-order information.

Experiment 2

In this experiment we examined sensitivity to second-order information by determining whether infants discriminate changes in the spacing between the eyes and between the nose and mouth in facial images. As noted in the Introduction, such spatial information constitutes the second-order relational information that expert humans (adults) use to process faces, according to Diamond and Carey (1986). Given that 3-month-olds failed to demonstrate sensitivity to second-order relational information as measured by the Thatcher illusion effect in Experiment 1, this experiment provided us with the opportunity to obtain convergent evidence of this lack of sensitivity at this age using a different stimulus manipulation.

We also examined whether 5-month-olds are sensitive to second-order information in this experiment. Given that 6-month-olds in the Bertin and Bhatt (2004) study had demonstrated sensitivity to second-order information as measured by the Thatcher illusion effect, the use of 5-month-olds allowed us to examine whether infants are sensitive to second-order information at an earlier age than 6 months while providing an age group to contrast with the performance of 3-month-olds. Thus, this experiment allowed us to examine developmental changes in sensitivity to second-order relations using a different procedure from previous research. It also allowed us to test younger infants than those previously shown to be sensitive to second-order relations.

Method

Participants. Sixteen 3-month-olds (M age = 104.56 days, $SE = 3.13$; 8 females, 8 males) and sixteen 5-month-olds (M age = 153.13 days, $SE = 2.20$; 9 males, 7 females) participated in this experiment. They were recruited in the same manner as those in Experiment 1. Infants were predominantly White and from middle-class backgrounds. An additional 15 infants (six 5-month-olds and nine 3-month-olds) were excluded from this study for crying ($n = 11$), falling asleep ($n = 3$) or failing to sample both test stimuli (i.e., position preference during the test, $n = 1$).

Stimuli. The stimuli were derived from those used in Experiment 1. The normal pattern was the same as the normal pattern in Experiment 1 except that some extraneous details such as the hair texture were erased and other features such as the lines demarcating the nose were modified to ensure that infants' attention was directed at the aspects of the face patterns that are critical to this study (see Figure 2). The second-order distorted pattern was created by increasing the spacing between the eyes and between the nose and the mouth of the normal pattern (see Figure 2). From the infants' position, the whole face image subtended 20.41° vertically and 17.93° horizontally. The horizontal distance between the eyes spanned 2.42° and 3.56° in the normal and second-order distorted images, respectively. The vertical gap between the nose and the mouth measured 0.51° and 1.14° in the normal and distorted faces, respectively. The 16 infants in each age group were habituated to the second-order distorted pattern and then tested for their preference between the normal and second-order distorted pattern. We chose to use only the distorted pattern during habituation rather than counterbalance the distorted and the normal pattern because Thompson et al. (2001) demonstrated that infants had a preference for normal faces over faces in which the spacing between features are changed, and we were concerned that the use of normal faces during habituation

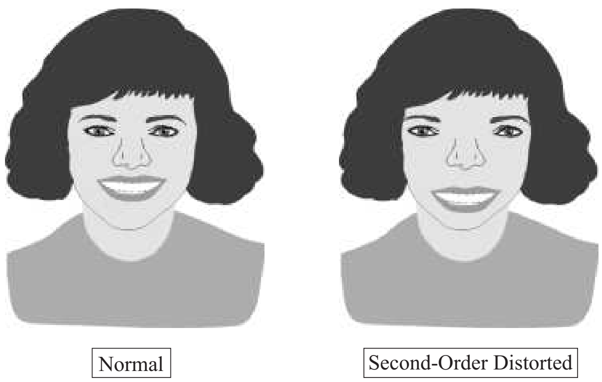

Figure 2. The stimuli used in Experiment 2. The actual face patterns shown to infants were in color.

might lead to the exhibition of a null preference during the test. This is because novelty preference might be counteracted by a spontaneous preference for the normal image in the case of infants habituated to the normal image. In this respect, we followed the lead of other studies in which the discrimination between normal and distorted faces was ascertained after habituation with the distorted image (e.g., Maurer & Barrera, 1981).

Apparatus and procedure. To ensure better experimental control, infants in this experiment were tested in a laboratory on campus, and stimulus presentations were on a computer monitor. The apparatus and procedure used were those that had been used in prior studies (e.g., Bhatt & Bertin, 2001; Bhatt, Bertin, & Gilbert, 1999). Infants were seated on their parents' lap about 45 cm in front of a 50-cm IBM monitor, which was located on the front panel of a darkened chamber. During the test sessions, the only source of light in the chamber was the monitor. A Sony CCD-FX430 camera, located on top of the monitor and connected to a TV monitor and a VCR, was used to monitor and record infants' looks. The TV monitor, VCR, and computer used to display the stimuli were located outside of the testing chamber.

As in Experiment 1, an infant control habituation procedure was used. Each trial began with the experimenter directing the infant's attention to the center of the computer monitor by presenting rapidly alternating square and circle colored patterns combined with taps on the back of the monitor. Once the infant's gaze was directed at the center of the monitor, the experimenter started the trial by pressing a computer key. At this time, two identical second-order patterns appeared on the screen, one to the left of the central fixation point and one to the right. Each habituation trial lasted until the infant looked away for 2 s or until 60 s had elapsed. Habituation trials were repeated until mean look duration of 3 consecutive trials was less than 50% of the mean look duration of the first 3 trials or until a maximum of 20 trials had elapsed.

Immediately after the last familiarization trial, infants were tested on two 10-s trials for their preference between the familiar second-order distorted pattern versus the normal pattern (Figure 2). The left–right locations of the normal and distorted faces in the first test trial were counterbalanced within each age group. The stimulus locations were switched for each infant during the second test trial.

Infants' performance during the test was coded offline by a trained observer who was unaware of the location of the novel test pattern. The video speed was reduced to 20% for coding. The performance of 10 infants was independently coded by another observer, and the interobserver reliability as measured by Pearson correlation was 0.97 ($SE = 0.02$).

Results and Discussion

Table 2 displays the mean fixation times of the two groups of infants during the first three and the last three habituation trials. An Age (3 months, 5 months) $\times$ Trial (first three, last three) ANOVA revealed only a Trial main effect, $F(1,\ 30) = 240.33$, $p < .001$. Neither the Age main effect nor the Age $\times$ Trial interaction effect was statistically significant, indicating the two age groups did not differ during the habituation phase of the experiment.

Table 2 also displays the mean novelty preference scores exhibited by the infants. Five-month-olds exhibited a novelty preference but 3-month-olds did not. A t test revealed that this difference was statistically significant, $t(30) = 2.63$, $p < .05$, two-tailed. Individual t tests revealed that the 5-month-olds' mean novelty preference score was significantly greater than the chance level of 50%, $t(15) = 2.77$, $p < .05$, two-tailed, whereas the 3-month-olds' score was not, $t(15) = -1.19$. $p > .05$, two-tailed.

These results clearly indicate a difference in the performance of 3- and 5-month-olds. Three-month-olds failed to discriminate changes in the spatial relations among facial features that have been characterized as second-order relational changes, but 5-month-olds exhibited sensitivity to the same changes. As in Experiment 1, where 3-month-olds failed to exhibit sensitivity to changes in second-order information (as induced by thatcherization), 3-month-olds in this experiment failed to exhibit sensitivity to second-order changes induced by the manipulation of the space between the eyes and between the nose and the mouth.

Table 2
Mean (and Standard Error) of Fixation Duration During Habituation Trials and Percentage Novelty Preference Exhibited During Test Trials in Experiment 2

	First three familiarization trials (s)	Last three familiarization trials (s)
3-month-olds	48.97 (3.04)	20.67 (2.28)
5-month-olds	47.99 (2.29)	15.96 (1.66)

	Preference (%) for novel pattern during test trials			
	M (SE)	N	t (vs. chance)	p (two-tailed)
3-month-olds	45.99 (3.34)	16	– 1.19	> .05
5-month-olds	57.08 (2.55)	16	2.77	< .05

As noted in the Method section, all infants in this experiment were habituated to the second-order distorted pattern and tested for preference between this pattern and the normal pattern. It is not clear, therefore, whether 5-month-olds' discrimination of second-order changes was due to a novelty preference for the normal face or solely reflected a spontaneous preference for normal faces over distorted faces (Thompson et al., 2001). To examine this issue, an additional group of sixteen 5-month-olds was subjected to the same preference tests used in this experiment except that these infants were not habituated to any stimuli. Infants failed to exhibit any preference during these spontaneous preference tests: Their mean preference for the normal face, 46.07% ($SE = 4.11$), was not significantly different from the chance level of 50%, $p > .35$. These results suggest that the 5-month-olds' preference for the normal face over the distorted face in Experiment 2 was a novelty preference rather than a spontaneous preference for the normal face.

Experiment 3

In Experiments 1 and 2, 3-month-olds failed to discriminate second-order changes that older infants discriminated. These results suggest that 3-month-olds are not sensitive to second-order information. The question then arises as to whether they are sensitive to other kinds of relational information, specifically, first-order relations. As noted previously, there is a considerable amount of research indicating that infants this age and younger are sensitive to first-order relations (e.g., Maurer & Barrera, 1981; Quinn & Slater, 2003; Simion et al., 2003). However, to contrast the lack of second-order processing by 3-month-olds in Experiments 1 and 2 with the possibility of first-order processing, it is important to demonstrate with the same stimuli and the same procedure used in these experiments that infants this age are sensitive to first-order information. This was the goal of the current experiment. Specifically, 3-month-olds were tested for their ability to discriminate first-order relational changes using the same stimuli and procedure that were used in Experiment 2.

Method

Participants. Sixteen 3-month-olds (M age = 97.4 days, $SE = 1.7$; 8 females, 8 males), recruited in the same manner as infants in previous experiments, participated in this study. Data from an additional 7 infants were discarded because the infants cried during the test ($n = 5$) or because they exhibited a position preference during the test ($n = 2$).

Stimuli. The normal (unaltered) face pattern was the same as the normal pattern used in Experiment 2 (Figure 3). The first-order distorted pattern (Figure 3) was created by scrambling the positions of the face components in such a manner that the typical categorical relations that define faces (e.g., the eyes above the nose) were violated.

Apparatus and procedure. The apparatus and procedure were the same as those used in Experiment 2. Infants were habituated to the first-order distorted pattern and tested for their preference between this pattern and the normal pattern.

Results and Discussion

The mean look duration during habituation and the mean novelty preference scores exhibited by the 3-month-olds are shown in Table 3. Infants discriminated the first-order change. A t test revealed that

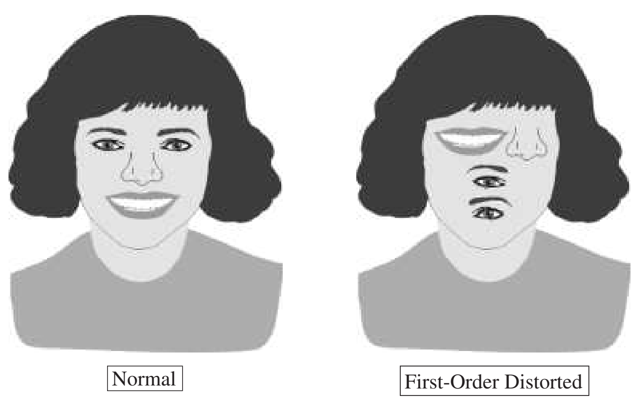

Figure 3. The stimuli used in Experiment 3. The actual face patterns shown to infants were in color.

the mean novelty preference score exhibited by the infants in this study was significantly greater than the chance level of 50%, $t(15) = 2.79$, $p < .05$. Thus, although 3-month-olds failed to discriminate second-order information in Experiment 2, they discriminated first-order information in the same face pattern in this experiment. These results suggest a difference in the developmental trajectories of sensitivity to first-order versus second-order relational information in faces.

Experiment 4

Typically, adults' processing of inverted faces is less accurate than that of upright faces (e.g., Carey & Diamond, 1977; Diamond & Carey, 1986; Freire et al., 2000; Murray et al., 2003; Rakover & Teucher, 1997; Rose et al., 2002; Tanaka & Farah, 1993, 2003; Yin, 1969). Face inversion appears to affect differentially relational processing compared with featural processing (Bartlett & Searcy, 1993; Young, Hellawell, & Hay, 1987). Tanaka and Farah (1993), for instance, found that face recognition based on individual features was affected less by inversion than recognition based on the whole face. More specifically, inversion appears to affect second-order relational information processing more than the processing of featural and other kinds of relational information (Collinshaw & Hole, 2000; Freire et al., 2000; Le Grand, Mondloch, Maurer, & Brent, 2001; Murray et al., 2003; Murray et al., 2000; Searcy & Bartlett, 1996).

Inversion also affects face processing in infancy (e.g., Bertin & Bhatt, 2004; Cashon & Cohen, 2003; Kestenbaum & Nelson, 1990; Roder, Bates, Crowell, Schilling, & Bushnell, 1992; Simion et al., 2003; Slater, Quinn, Hayes, & Brown, 2000). Bertin and Bhatt (2004), for instance, found that 6-month-olds detect thatcherization in upright but not inverted faces. This result is consistent with the idea that inversion affects second-order relational processing.

Maurer et al. (2002) suggested that if it could be demonstrated that inversion affects the processing of a particular kind of stimulus manipulation more than another, it would be evidence that face processing involves the kind of information that is affected by this manipulation. In the present experiment, therefore, we examined whether 5-month-olds' processing of second-order information is differentially affected by face inversion. We contrasted the effects of face inversion on the processing of faces in which the spatial relations were distorted to affect second-order relations with the processing of faces in which the spatial relations were distorted to affect first-order relational information (Figure 4).

One group of 5-month-old infants was tested with the same stimuli that infants this age had discriminated in Experiment 2 except that now the stimuli were presented upside down (Figure 4). The performance of this group was contrasted with another group that was also tested with inverted stimuli, but in this case the distorted face differed from the normal face in terms of first-order relations (Figure 4). If infants' performance is affected by inversion in the second-order condition but not in the first-order condition, it suggests that face processing at this age involves the use of second-order information (Maurer et al., 2002).

Method

Participants. Thirty-two 5-month-olds (M age = 146.13 days, $SE = 1.23$; 18 females, 14 males) participated in this experiment. They were recruited in the same manner as the infants in Experiments 1 and 2. An additional 9 infants were tested but not included in the study for crying ($n = 7$), falling asleep ($n = 1$), or failing to sample both test stimuli (i.e., position preference during the test, $n = 1$).

Stimuli. The stimuli are displayed in Figure 4. The stimuli used in the second-order condition were the same as those used in Experiment 2 except that the stimuli were presented upside down in this experiment. The stimuli used in the first-order condition were the same as those used in Experiment 3 except that the stimuli were presented upside down in this experiment. Note that the stimuli were presented upside down during both habituation and test in both conditions.

Apparatus and procedure. The apparatus and procedure were exactly the same as those used in Experiments 2 and 3.

Table 3
Mean (and Standard Error) of Fixation Duration During Habituation Trials and Percentage Novelty Preference Exhibited During Test Trials in Experiment 3

First three familiarization trials (s)	Last three familiarization trials (s)
50.28 (2.40)	19.22 (2.22)

Preference (%) for novel pattern during test trials

M (SE)	N	t (vs. chance)	p (two-tailed)
58.94 (3.20)	16	2.79	< .05

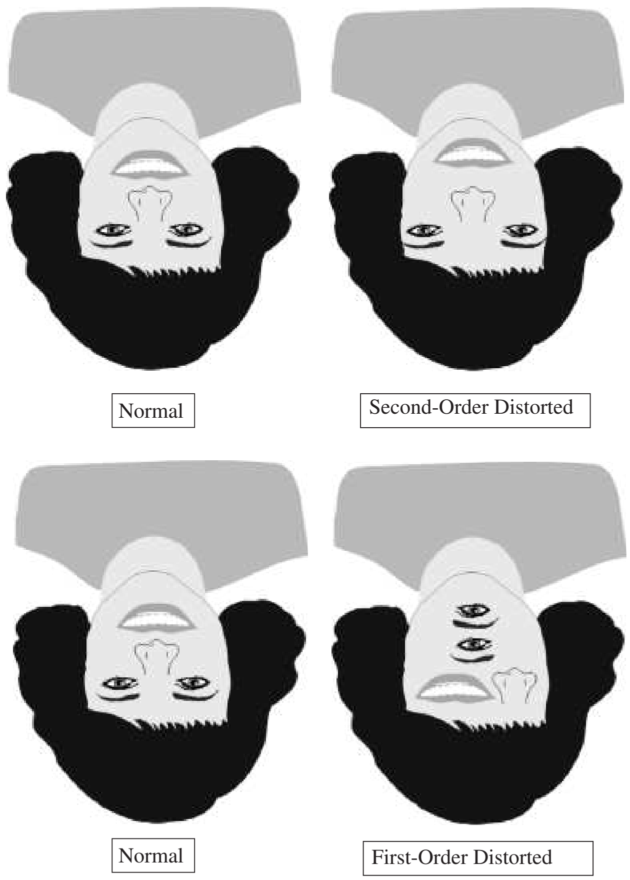

Figure 4. The stimuli used in Experiment 4. Infants in both the second-order and first-order distorted conditions were habituated and tested with inverted stimuli. The actual face patterns shown to infants were in color.

Table 4
Mean (and Standard Error) of Fixation Duration During Habituation Trials and Percentage Novelty Preference Exhibited During Test Trials in Experiment 4

	First three familiarization trials (s)	Last three familiarization trials (s)
First order	26.83 (3.23)	9.04 (1.30)
Second order	36.24 (3.52)	13.03 (1.80)

	Preference (%) for novel pattern during test trials			
	M (*SE*)	*N*	*t* (vs. chance)	*p* (two-tailed)
First order	58.69 (3.68)	16	2.36	$<.05$
Second order	44.69 (3.44)	16	-1.83	$>.05$

Results and Discussion

Infants' mean look durations during the first three and the last three habituation trials are shown in Table 4. A Group (first-order, second-order) $\times$ Trial (first three, last three) ANOVA revealed a significant Trial main effect, $F(1, 30) = 139.71$, $p < .001$, and a marginally significant Group main effect, $F(1, 30) = 4.12$, $p = .051$. The interaction between the two factors was not statistically significant. The marginal Group effect indicates that the inverted second-order face pattern elicited longer looking than the inverted first-order face pattern during habituation. However, as required by the infant control procedure, both groups of infants were habituated to the same criterion of 50% decline in look duration before being tested.

Table 4 displays the novelty preference scores exhibited by infants in the first-order and second-order conditions. Infants in the first-order condition discriminated a change but those in the second-order condition failed to discriminate any changes. A *t* test revealed that this difference was statistically significant, $t(30) = 2.98$, $p < .01$, two-tailed. Individual *t* tests also revealed that the mean novelty preference exhibited by the first-order group was significantly greater than the chance level of 50%, $t(15) = 2.36$, $p < .05$, two-tailed, whereas the novelty preference score exhibited by the second-order group was not significantly different from chance, $t(15) = -1.83$, $p > .05$, two-tailed.

These results indicate that the second-order relational changes that were discriminated when the face pattern was presented upright in Experiment 2 were not discriminated when the pattern was presented upside down in this experiment. Thus, inversion affected the discrimination of second-order relational information. However, inversion did not affect the processing of first-order relations. This dissociation between the effects of these two kinds of changes suggests that, although both first-order and second-order relations are processed by 5-month-olds, second-order information processing is more vulnerable to disruption than is first-order information processing. In this respect, 5-month-olds' performance is similar to that of adults (e.g., Collinshaw & Hole, 2000; Freire et al., 2000; Murray et al., 2003; Murray et al., 2000; Searcy & Bartlett, 1996).

General Discussion

The current experiments revealed that infants as young as 5 months of age are sensitive to second-order relational information in faces, the fine spatial relations among features that are thought to underlie expert face processing by adult humans. However, 3-month-olds failed to process such information, suggesting that sensitivity to second-order relational information in faces develops sometime between 3 and 5 months of age. At the same time, 3-month-olds discriminated first-order relational information, indicating a dissociation in the development of the ability to use these two kinds of relational information. The current results also indicate that in infancy, as in adulthood, processing of second-order information is more easily disrupted than the processing of first-order information.

As noted previously, there is some evidence indicating that even children as old as 14 years of age may not use second-order relational information to the same extent as adults (e.g., Carey & Diamond, 1994; Freire & Lee, 2001, 2003; Mondloch et al., 2002, 2003; Schwarzer, 2000). Qualitative changes from childhood to adulthood in the neural mechanisms involved in the processing of facial information have also been documented (e.g., Gathers, Bhatt, Corbly, Farley, & Joseph, 2004). On the other hand, some other researchers have argued that the developmental changes from childhood to adulthood are based only on general across-the-board quantitative changes in performance rather than on qualitative differences in the use of different kinds of information (e.g., Flin, 1985; Itiera & Taylor, 2004; Tanaka & Farah, 2003; Want et al., 2003). The current research indicates that infants as young as 5 months of age might be sensitive to second-order information. Of course, this finding does not resolve the debate about whether there are qualitative changes in face processing from childhood to adulthood, but it indicates that the ability to process second-order information is available relatively early in life; therefore, any developmental changes found later in life are not based on an inability to process this kind of information.

It should be noted that the spacing changes used in Experiments 2 and 4 were large and may not reflect the normal degree of differences associated with faces in terms of second-order information. Changes that are within the normal range may not be discernible by 5-month-olds or even older infants (Le Grand, Maurer, & Mondloch, 2004; Shannon et al., 2004). Thus, the question of whether the sensitivity to second-order information exhibited by the 5-month-olds in our laboratory experiments is indicative of the use of such information in the real world by infants this age remains unanswered. Research addressing this issue will have to take into consideration the range of variation among faces in terms of featural and second-order information and the multitude of other cues that are available to discriminate among faces in the typical social environment of infants.

Although sensitivity to second-order information was evident by 5 months of age in the current experiments, such sensitivity was not exhibited by 3-month-olds. Three-month-olds failed to discriminate second-order changes that were induced by thatcherization in Experiment 1, whereas 6-month-olds discriminated the same changes in Bertin and Bhatt (2004). Similarly, 3-month-olds failed to detect second-order changes induced by the manipulation of the spacing between facial components in Experiment 2, whereas 5-month-olds discriminated the same changes. The convergence of the evidence from these two different kinds of stimulus manipulation strengthens the conclusion that 3-month-olds are insensitive to second-order information.

This developmental change from 3 to 5 months of age is consistent with other research that has indicated developmental changes in the processing of relational information over this age range (e.g., Cashon & Cohen, 2003; Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002; Younger & Cohen, 1986). Cashon and Cohen (2003), for example, found that when exposed to two faces concurrently, 3-month-olds process only the individual features and do not integrate the features from the different faces into separate wholes. In other words, 3-month-olds do not appear to process what goes with what. In contrast, 4-month-olds were able to process this information.

The developmental change in the processing of second-order information is also consistent with several neuronal models of the development of face processing (Acerra et al., 2002; Gauthier & Nelson, 2001; Mondloch et al., 2003; Morton & Johnson, 1991; Nelson, 2003). Two prominent models, the CONSPEC-CONLERN model proposed by Morton and Johnson (1991) and the model proposed by Acerra et al. (2002), assume that experience of face processing after the first few weeks and months interacts with brain structures to allow sophisticated processing of facial information. The Acerra et al. model assumes that the development or activation of the fusiform area of the right hemisphere allows the processing of configural information. Support for this assumption comes from studies by Maurer, Mondloch, Le Grand, and colleagues (Mondloch et al., 2003) that show visual deprivation during the first months of life, especially caused by the lack of processing by the right hemisphere (induced by cataracts), results in abnormal development of sensitivity to second-order relations.

Although the current results are consistent with both cognitive and neuronal models of face processing, they also could constrain such models. For instance, such models would have to explain why there is a specific change from 3 to 5 months in the processing of second-order relational information. They also need to explain why second-order relational processing is vulnerable to disruption by manipulations such as inversion but first-order relational processing is not.

The failure of 3-month-olds to exhibit sensitivity to second-order information in our experiments should not be taken to mean that infants this age are unable to process spatial relational information in faces. Experiment 3 indicated that 3-month-olds are sensitive to gross, categorical spatial relations or first-order relational information. Also, as noted previously, even newborns appear to be sensitive to face-like configurations (Simion et al., 2003). Moreover, 3-month-olds have been shown to extract prototypes after experience with a series of faces in an experimental setting, indicating that they are able to process the differences across faces, average across these faces, and form prototypes (de Haan, Johnson, Maurer, & Perrett, 2001). Similarly, research by Langlois and colleagues (e.g., Hoss & Langlois, 2003) suggests that 2- to 3-month-olds prefer to look at attractive faces more than at unattractive faces, and at least in older infants this attractiveness effect has been attributed to preference for prototypical average faces. Yet, the current research suggests that 3-month-olds are not sensitive to second-order relations under conditions in which older infants process the same information. However, even 3-month-olds might exhibit evidence of sensitivity to second-order information under different conditions. For example, 3-month-olds might process second-order information if the face stimuli used contained motion, shading, or other kinds of three-dimensional cues.

The dissociation in the developmental trajectories of sensitivity to first-order versus second-order relations documented in Experiments 1 and 2, and the finding in Experiment 4 that inversion disrupts second-order but not first-order information processing are consistent with the qualitative distinction that several researchers have made between these two kinds of relational information processing in adulthood (Carey & Diamond, 1994; Diamond & Carey, 1986; Murray et al., 2003; Murray et al., 2000; Mondloch et al., 2003). In fact, the finding that inversion affected second-order processing but not first-order processing suggests a similarity in face processing between infants and adults in that several studies on adults have found that inversion affects the processing of second-order relations more than the processing of first-order or featural information (Collinshaw & Hole, 2000; Freire et al., 2000; Le Grand et al., 2001; Murray et al., 2003; Murray et al., 2000; Searcy & Bartlett, 1996). However, although the mechanisms of face processing in 5-month-olds may be similar to the mechanisms in adults, they are likely not exactly the same, given that even children as old as 14 years of age may not process faces in the same manner as adults.

It should be noted that the current studies do not speak directly to the issue of whether second-order and first-order relations are qualitatively or just quantitatively different. Prior studies have documented qualitative differences in the processing of categorical spatial information (e.g., above–below) versus detailed spatial information (e.g., metric distances between objects; e.g., Huttenlocher, Hedges, & Duncan, 1991; Quinn, 1994), and it is possible that the first-order/second-order distinction made in the literature on face perception is a similar qualitative contrast. On the other hand, it is possible that the developmental changes and the dissociation between first-order and second-order information processing obtained in the current experiments reflect the quantitatively different level of difficulty posed by the two kinds of information, with second-order information being inherently more subtle and harder to discriminate than first-order information. Future research will have to distinguish between these accounts.

In summary, the current research indicates that a hallmark of expert face processing in adulthood—the ability to process second-order relational information—is available as early as 5 months of age. However, 3-month-olds do not appear to be sensitive to this kind of information. Face processing, like language, is a cognitive function that is critical for effective social functioning, and the findings from the current experiments suggest that although many aspects of this function are operational within the first 5 months of age, there may also be significant developmental changes during this period.

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The still-face response in newborn, 1.5-, and 3-month-old infants

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Abstract

The present study investigated the still-face response to a female stranger in newborn, 1.5-, and 3-month-old infants. The results revealed that 1.5- and 3-month-olds, but not newborns, reliably decreased their visual attention and positive affect when the interaction partner became unresponsive during the still-face period.

Keywords: Still-face; Gazing; Smiling; Social interaction; Newborns

Humans are born with a readiness to communicate and connect with other people. Shortly after birth, infants prefer human stimuli such as face-like compared to non-face-like patterns and human over non-human sounds (e.g., Friedlander, 1970; Johnson, Dziurawiec, Ellis, & Morton, 1991). Moreover, very young infants imitate facial gestures and emotional expressions (e.g., Field, Woodson, Greenberg, & Cohen, 1983; Meltzoff & Moore, 1989), which has been explained both in terms of perceptual cross-modal matching and the fundamental need for interpersonal communication (Trevarthen, 1993). These findings suggest an early sensitivity to social stimuli and a readiness for interpersonal contact.

Newborns' draw to social stimuli provides the necessary basis for acquiring knowledge about the nature of interpersonal interactions. One of the most robust procedures to test infants' understanding of natural interaction patterns is the still-face (SF) paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978). In this paradigm, a normal face-to-face interaction between an infant and an adult is interspersed with a period in which the adult suddenly freezes, becomes unresponsive, and poses a stationary neutral face while maintaining eye contact. Infants as young as 2 months of age react to the adults' unresponsiveness during the SF period with decreased visual attention and positive affect (e.g., Lamb, Morrison, & Malkin, 1987; Tronick et al., 1978). Such results are interpreted in terms of infants' affective attunement to social patterns and rudimentary expectations about the nature of face-to-face interactions (e.g., Muir & Hains, 1993).

The majority of studies examined the SF response in infants between the age of 2 and 9 months (see Adamson & Frick, 2003). Therefore, the question of whether, and to what extent, younger infants respond to perturbed adult

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interactive behavior remains. In the current study, we investigated the development of the SF effect in the first months of infancy. There are at least two reasons why infants younger than 2 months might exhibit the SF response. First, the SF paradigm is characterized by many perceptual differences between the interactive and SF period. It is plausible that even newborn infants, who possess many perceptual capabilities (e.g., Slater, 1997, for a review), are sensitive to these changes. Second, given the prevalence and importance of responsive and reciprocative face-to-face interactions in Western cultures (e.g., Bornstein, Azuma, Tamis-LeMonda, & Ogino, 1990), a rudimentary understanding of the nature of dyadic interactions might form rapidly and be in place even before 2 months of age. By testing newborns, we were able to examine whether the SF response mainly rests upon postnatal development and social experiences or if it perhaps is innate.

Although the typical response to a still-face manifests itself in both gaze *and* smile, it is possible that in young infants one of the signature behaviors prevails over the other. By observing infants in the SF paradigm before and at 3 months of age, we were able to examine if the SF response progresses from mainly visual attentive in younger infants to both visual and affective in older infants, or whether the signature responses always occur together.

Eighteen newborns (9 females, 9 males; $M = 3.67$ days, S.E. = 0.36), eighteen 1.5-month-olds (10 females, 8 males; $M = 46.61$ days, S.E. = 1.24), and eighteen 3-month-olds (7 females, 11 males; $M = 95.44$ days, S.E. = 2.08) participated in this experiment. An additional 20 infants (eleven newborns, seven 1.5-month-olds, and two 3-month-olds) were tested but not included in the study because of fussiness ($n = 10$; six newborns, three 1.5-month-olds, and one 3-month-old), sleepiness ($n = 9$; five newborns, four 1.5-month-olds), and parental interference ($n = 1$; 3-month-old). All participants were healthy and full-term, and recruited from a city hospital of a mid-size Germany town.

Newborns were tested in a quiet room at the hospital at a time when they were alert (i.e., eyes open and attention directed toward external stimuli) usually midway between morning feedings. 1.5- and 3-month-olds were tested in a laboratory room at the research institute. Infants were seated in an infant seat (reclined 30°). A female experimenter (E1) stood bent forward in front of the infant to allow face-to-face interaction. E1 engaged with each infant in a 180-s interaction episode that was divided into three consecutive 60-s periods. Testing always began and ended with a 60-s normal interaction period (N1 and N2, respectively) in which the experimenter smiled, vocalized, and responded to any communicative overture infants exhibited. The normal interaction periods were separated by a 60-s SF period in which the experimenter posed a stationary, silent still-face with neutral expression while maintaining eye contact. E1 did not touch the infant throughout the entire 180-s interaction episode. The experimental sessions were video recorded.

For each 60-s interaction period, the duration of infants' *Gazing* and *Smiling* was coded from video tapes by an observer who was blind to the hypotheses of the study. Duration scores were converted into percent durations. *Gazing* was defined as any looks to the experimenter's face. *Smiling* was defined as cheeks raised and at least one corner of the mouth turned up while gazing. Inter-rater reliability was computed on 18 participants yielding Cohen's kappa .94 for gazing and .91 for smiling.

An age group (*newborns, 1.5-month-olds, 3-month-olds*) × period (*N1, SF, N2*) mixed design ANOVA for *Gazing* yielded an age group main effect, $F(2,51) = 7.46$, $p < .01$. Least significant difference (L.S.D.) pair-wise comparisons indicated that newborns gazed significantly less at E1 than both 1.5- and 3-month-old infants. A main effect for period was also observed, $F(2,102) = 9.74$, $p < .001$, with L.S.D.s pointing to a significant decrease in looking toward E1 during the SF than both the N1 and N2 period. One-way ANOVAs revealed that, while infants did not differ in gazing duration in the SF period ($p > .05$), newborns spent significantly less time looking at E1 than 1.5- and 3-month-olds in the both normal interaction periods (all ps < .03). No other comparisons reached significance (Fig. 1).

One-way repeated measures ANOVAs revealed no quadratic trends for newborns' gazing pattern, $F(1,17) = 1.97$, $p > .1$. However, the decrease in looking at E1 from N1 to the SF period reached marginal significance ($p = .077$). The looking pattern of both 1.5- and 3-month-olds was defined by a significant quadratic effect ($F(1,17) = 12.25$, $p < .01$; $F(1,17) = 17.99$, $p < .01$, respectively). Specifically, while 3-month-olds gazed at E1 significantly less in the still-face compared to both normal interaction periods (ps < .005), 1.5-month-olds significantly decreased their looking only from the first normal to the SF period ($p < .005$).

The age group (*newborns, 1.5-month-olds, 3-month-olds*) × period (*N1, SF, N2*) mixed design ANOVA for *Smiling* yielded significant main effects for age group ($F(2,51) = 4.94$, $p < .02$) and period ($F(2,102) = 9.95$, $p < .001$). Follow-up L.S.D.s revealed that newborns smiled significantly less than both 1.5- and 3-month-olds (ps < .02), and that infants smiled more in the normal interaction periods than in the SF period (ps < .03). The interaction effect also reached significance ($F(4,102) = 2.55$, $p < .05$). The one-way ANOVAs for *Smiling* revealed the same pattern as for *Gazing*, in that infants' duration of smiling did not differ during the SF period ($p > .05$), but was significantly less for newborns

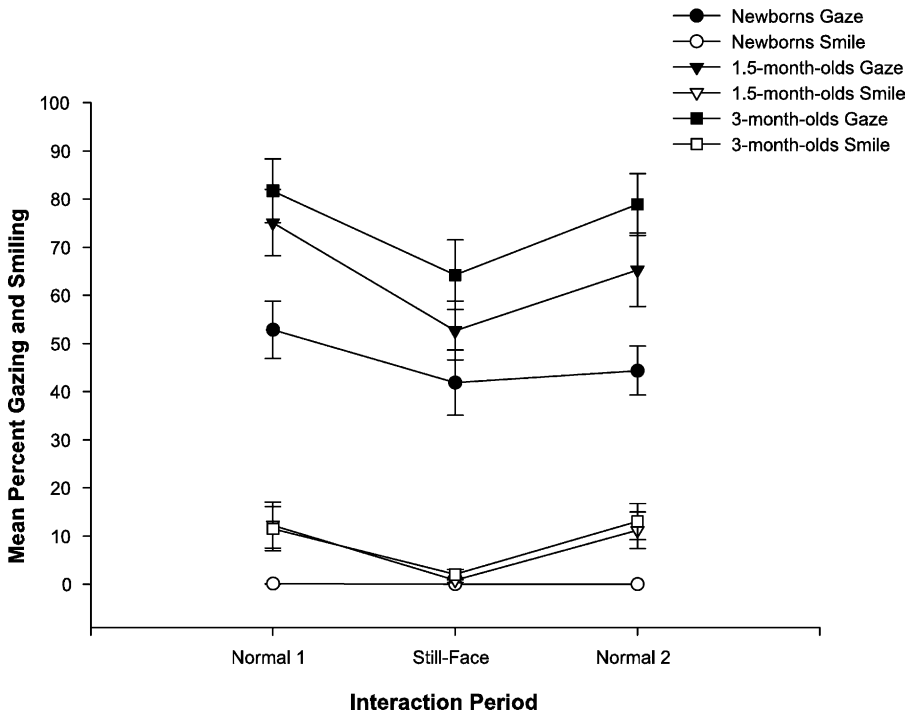

Fig. 1. Mean percent duration of Gazing and Smiling as a function of interaction period and group.

than both older age groups during N1 and N2 (*p*s < .05). The quadratic trends of *Smiling* were significant for both older age groups (1.5-month-olds: $F(1,17) = 8.43$, $p < .03$; 3-month-olds: $F(1,17) = 8.38$, $p < .02$), but not for newborns ($F(1,17) = 1.0$, $p > .1$). The quadratic trends for 1.5- and 3-month-olds revealed that infants smiled at E1 significantly less in the SF compared to both normal interaction periods (*p*s < .05) (Fig. 1).

While the SF effect was similarly observed in 1.5- and 3-month-olds, newborns—despite their perceptual abilities across modalities and their predisposed sensitivity to social stimuli—did not reliably change their behavior relative to the interaction periods. Although gaze patterns are qualitatively similar for all age groups (see Fig. 1), the data point to age-related differences in the visual response to perturbations in natural interaction patterns. For example, newborns' drop in visual attention from N1 to SF was only tendential while it was significant for 1.5- and 3-month-olds. Only 3-month-olds showed the effect-typical increase in visual attention during the re-engagement period, while both newborns' and 1.5-month-olds' recovery from SF to N2 was insignificant. Moreover, 1.5- and 3-month-olds accompanied their visual attentive behavior with positive affect. Thus, while similarities in the patterns of the SF responses were observed, the data seem to suggest that infants' reactions to social perturbations grow more robust between the age of 0 and 3 months. Contrary to our assumption, we did not find that the SF effect progresses from mainly visual attentive in younger infants to both visual and affective in older infants.

In a study with 2-day-olds, Ellsworth (1987, cited in Muir & Hains, 1993) found that, as in the current study, newborns' visual attention was high in N1, abated in the SF period, and more or less plateaued when the female stranger resumed responsiveness. Moreover, Ellsworth's newborns also failed to exhibit affect during any interaction period. While some emotional expressive patterns can be present at birth (e.g., Galati & Lavelli, 1997), the short 3-min observation period, the overall similarity between the interaction periods (only vocal sound and corresponding facial movement ceased during SF), or the general difficulties inherent in measuring and interpreting newborns' emotions might have impeded the observation of newborns' emotional expressions in the current study.

While previous research has also revealed robust SF responses in 3-month-olds (e.g., Ellsworth, Muir, & Hains, 1993; Toda & Fogel, 1993), systematic investigations with younger infants have been scarce. In the current study, we measured only the signature SF behaviors of gazing and smiling (see also, Rochat, Striano, & Blatt, 2002). Employing this procedure, we did not find a strong SF effect in newborns. Newborns might be sensitive to the differences between a responsive and an unengaged social vis-à-vis, but simply lack the expressive repertoire to reveal their knowledge.

Maturation and continuous visual attention to social partners might lead to more mature SF responses. Thus, the observed behavioral patterns of newborns might constitute the precursor for such behavior.

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Contribution of facial and vocal cues in the still-face response of 4-month-old infants

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Abstract

The contribution of contingent facial and vocal information in the still-face effect was investigated. Four-month-old infants either saw and heard their mother, only saw their mother, or only heard their mother interacting with them. These interaction periods were followed by the cessation of the mother's interactive face and/or voice. Only infants who observed their mother's face become still and neutral, showed a still-face effect by decreasing their visual attention and positive affect. The findings provide further support that the mother's interactive voice does not contribute to the still-face effect. The developing sensitivity to vocal information in dyadic and triadic contexts is discussed.

Keywords: Still-face; Vocal cues; Facial cues; Infant social development

1. Introduction

From as early as 2 months of age, human infants reliably express social expectations in relation to people. One of the most reliable paradigms to assess what infants understand and expect from other people is the still-face paradigm (Adamson & Frick, 2003). In this paradigm, an adult, often the infant's mother or sometimes a stranger interacts with the infant in a normal face-to-face interaction. Then, the adult suddenly freezes, becomes unresponsive, and poses a stationary neutral face. This still-face period is typically followed by another normal face-to-face interaction. The whole interaction episode usually lasts a couple of minutes. This procedure, and variations of it, has been used for over 25 years across a wide

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range of ages, populations, and experimental contexts (e.g., Carvajal & Iglesias, 1997; Ellsworth, Muir, & Hains, 1993; Gusella, Muir, & Tronick, 1988; Nadel, Croue, Mattlinger, Canet, Hudelop, & Lecuyer, 2000; Pelaez-Nogueras, Field, Hossain, & Pickens, 1996; Tronick, Als, Adamson, Wise, & Brazelton, 1978). Research reveals that infants as young as 2 months of age react to the adults' unresponsiveness during the still-face period with decreased visual attention and positive affect, and increased self-comforting behaviors (e.g., Lamb, Morisson, & Malkin, 1987; Murray & Trevarthen, 1985; Tronick et al., 1978). In general, results show that human infants have rudimentary expectations about the nature of face-to-face interactions—they expect people to remain responsive and reciprocate in interpersonal interactions (e.g., Ellsworth et al., 1993; Muir & Hains, 1993; Rochat & Striano, 1999).

While the still-face paradigm is robust in nature, it is limited in some ways. In particular, the still-face period constitutes a dramatic and abrupt change from normal ongoing caregiver–infant interaction. During the still-face period, the infant loses maternal social contingency and reciprocity, display of maternal emotions conveyed by vocal and facial information, and often maternal touch (see Muir, 2002; Muir & Hains, 1999). To examine the separate roles of these factors in producing the still-face effect, researchers have developed a TV interaction procedure whereby mothers and infants interact over closed-circuit TV monitors (e.g., Gusella et al., 1988; Hains & Muir, 1996; Muir & Hains, 1993; Murray & Trevarthen, 1985; see also Nadel & Tremblay-Leveau, 1999). This paradigm allows only particular aspects of the interaction to be manipulated while holding other aspects constant.

Using the TV interaction procedure, Gusella et al. (1988) conducted a systematic investigation into the separate contributions of maternal facial and vocal expressions in producing the still-face effect. Six-month-old infants interacted with their mothers via closed-circuit color TVs in one of four conditions. Each condition started and ended with a 90-s normal face-to-face interaction period between mother and infant. These two normal periods were separated by either a *Still face/No voice* period (infants saw their mother's expressionless, silent still-face), *Still face/Interactive voice* period (infants saw their mother pose a still-face while hearing her contingent voice), *Interactive face/No voice* period (infants saw their mother's interactive face, but did not hear her voice), or *Interactive face/Interactive voice* (infants saw their mother's interactive face and heard her interactive voice). The results revealed that when the interactive face of the mother became neutral and void of expressions during the second interaction period (*Still face/No voice* and *Still face/Interactive voice* condition), infants gazed and smiled less towards her, even if the mother's contingent, interactive voice continued into this period. For infants whose mother's interactive face continued into the second interaction period (*Interactive face/No voice* and *Interactive face/Interactive voice*), no decline in gaze and smile was observed relative to the normal interaction period. As long as there was a still-face, regardless of whether or not it was accompanied by an audible interactive voice, infants manifested a still-face response. As argued by the authors, a loss of contingent vocal cues does not lead to a still-face effect (see also Muir & Hains, 1999).

In some sense, this result is not surprising. Clearly, the face plays an important role in early social expectations—especially in Western cultures where face-to-face contact is prevalent (see Rochat & Striano, 1999). However, in another sense it is surprising that the voice does not influence the still-face response, given that much interaction between infants and adults also involves the voice. In many cultures infants are carried on a caregiver's back, making vocal exchanges more important. Even in Western cultures infants are often engaged in vocal interactions with caregivers that are out of sight or while being pushed in carriages. The voice also seems to play an important role in triadic contexts such as social referencing. At 12 months of age infants use vocal cues in social referencing even when not accompanied by facial cues (e.g., Vaish & Striano, 2004; see also Mumme, Fernald, & Herrera, 1996). Thus, the question why the voice does not appear to modulate the still-face response remains.

The current study was designed to extend upon the results of Gusella et al. (1988). In particular, we assessed whether infants manifested a still-face response when visual and vocal cues were not in conflict. It is possible that infants in the Gusella et al. study were perturbed in the *Still face/Interactive voice* condition because of the conflicting information they received. That is, infants may have had developed expectations that motionless, neutral still-faces are generally not accompanied by contingent vocal information. Prior research shows that infants expect faces and voices to provide congruent information (see Walker-Andrews, 1997, for a review). On the other hand, infants in the *Interactive face/No voice* condition might have been less disturbed given that they might have had the experience of observing people talking without necessarily hearing them (e.g., when people whisper or when people are watched from a distance). In the current study we explored these alternatives in a live interaction paradigm.

During mother–child interactions, infants received either contingent facial and vocal information (*Face plus Voice*), only contingent facial information (*Face only*), or only contingent vocal information (*Voice only*). The *Voice only* condition in the present study differed from the *Still face/Interactive voice* in the Gusella et al. (1988) study in that the mother could be heard but no seen, and thus, no conflicting information was provided. Based on prior research suggesting that the voice is an important aspect of interaction (Mumme et al., 1996; Vaish & Striano, 2004), we expected that infants would manifest a still-face response in all experimental conditions.

2. Method

2.1. Participants

Thirty-six full-term infants participated in the study (M = 4 months 3 days, S.D. = 10.79 days, range = 3 months 10 days to 4 months 23 days; 21 males and 15 females). An additional 13 babies were tested but not included in the study due to fussiness (n = 10), distractedness (n = 1), and experimenter error (n = 2). Participants were recruited by telephone from a database consisting of a list of names of infants whose caregivers had volunteered to participate in studies of child development. All infants were full-term and healthy, and cared for at home primarily by their biological parents. Infants were White, living in the east of Germany, and were from middle-class families. Infants received a toy for their participation.

2.2. Procedure

Testing took place in a 3 m × 4.5 m room with white walls and curtains which prevented any visual distraction. Infants were seated in a commercial infant seat. Mothers sat either 0.5 m in front of the infants at eye level or stood behind the infant and out of his/her view depending on the condition. Infants and mothers engaged in a 180-s interaction episode that was divided into three consecutive 60-s periods. As infants became available, they were randomly assigned to one of three conditions. Infants in the *Face plus Voice* condition engaged first in a normal 60-s face-to-face interaction with their mothers who sat in front of them (P1). This was followed by a 60-s still-face period in which the mother stopped interacting with the infant and posed a stationary, silent, still-face with neutral expression (SF). Immediately thereafter, the mother resumed a normal face-to-face interaction with the infant for the last 60-s interaction period

(P2). The three interaction periods in the *Face only* condition were identical to the ones in the *Face plus Voice* condition except that caregivers mimicked natural interaction without emitting any audible speech sounds during the first (P1) and last (P2) 60-s interaction period. In the *Voice only* condition, the mother stood behind the infant and a curtain so as not to be within his/her visual field, but within audible distance to the infant. Mothers saw their infants on a TV monitor to ensure contingent vocal interaction. In all other regards, the three interaction episodes were identical to the ones in the *Face plus Voice* condition. Thus, during P1 and P2, the infant saw *and* heard the mother in the *Face plus Voice* condition, *only* saw the mother in the *Face only*, and *only* heard the mother in the *Voice only* condition. The SF period was identical in the *Face plus Voice* and the *Face only* condition (i.e., still-face, no interactive voice), whereas in the *Voice only* condition the infant did not see or hear the mother (i.e., no still-face, no interactive voice).

A research assistant, who was out of view for infant and mother, timed the interaction and verbally signaled to the mother the beginning of each interaction period. Mothers were instructed to look at their infants during all interaction episodes. Mothers were allowed to use their hands to engage their child's attention during P1 and P2 (*Face plus Voice*, *Face only*), but not to touch their infants. Infant–caregiver interactions were video-taped for later coding.

2.3. Coding

Interaction episodes were scored form video tapes by a trained coder blind to the hypotheses of the study. For each 60-s interaction period the duration of several infant behaviors were measured and converted into percentage durations. The dependent variables were operationally defined as follows:

Gaze (*Face plus Voice*, *Face only*): Any looks to mother's face.
Smile: Cheeks raised and at least one corner of the mouth turned up.
Positive Vocalization: Any vocalization accompanied by positive or neutral affect.
Negative Vocalization: Any whimpering or insistent grunting, but excluding crying.

To assess intercoder reliability, a second, naïve coder scored a random 20% of the interaction sessions. The agreement between the two coders was Cohen's kappa .87 for gaze, .85 for smile, .73 for positive vocalization, and .93 for negative vocalization. The percent agreement for all measures ranged from 94.5 to 99.8%.

3. Results

Preliminary results revealed no gender effects for any behavior or condition. Thus, the data were collapsed across this variable in subsequent analyses. Fig. 1 depicts the mean percent duration of gazing as a function of condition (*Face plus Voice*, *Face only*) and interaction period (*P1*, *SF*, *P2*). The still-face effect for *Gaze* was analyzed with one-way analyses of variance (ANOVA) in which interaction periods (*P1*, *SF*, *P2*) were treated as repeated measures. Separate repeated measures ANOVAs were conducted for the *Face plus Voice* and the *Face only* condition. The results revealed significant quadratic trends for both conditions (*Face plus Voice:* $F(1, 11) = 9.55$, $p < .05$; *Face only*: $F(1, 11) = 17.67$, $p < .01$) indicating that mean percentage duration of gazing at the mother's face during the still-face period was significantly lower than in the preceding P1 and proceeding P2 interaction periods. Furthermore, a condition (*Face plus*

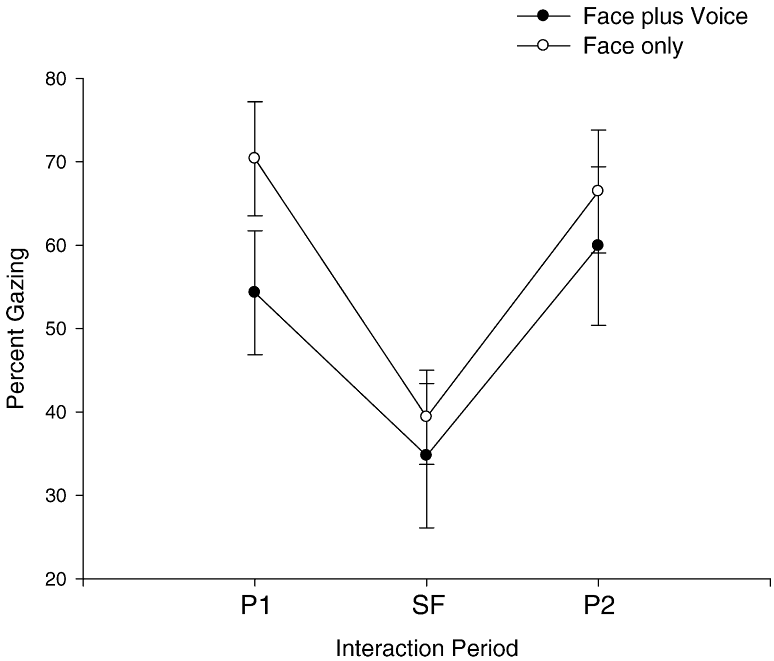

Fig. 1. Percent of gazing and standard error as a function of condition and interaction period.

Voice, *Face only*) × period (*P1*, *SF*, *P2*) mixed design ANOVA revealed no interaction effect ($F(2, 44) = .65$, $p > .05$), suggesting that infants' mean looking duration in the two conditions and three interaction periods did not significantly differ from each other.

Whether *Smiling* decreased during the still-face period was analyzed with one-way repeated ANOVAs for the *Face plus Voice*, *Face only*, and the *Voice only* conditions (see Fig. 2). Only the *Face only* condition yielded a significant quadratic trend, $F(1, 11) = 11.33$, $p < .05$, indicating that infants smiled significantly less during the still-face period than during the P1 and P2 periods. Not finding a still-face effect in the *Face plus Voice* condition was surprising and perhaps due to low power. A condition (*Face plus Voice*, *Face only*, *Voice only*) × period (*P1*, *SF*, *P2*) mixed design ANOVA yielded a condition main effect, $F(2, 33) = 6.72$, $p < .01$. Least significant difference (LSD) pair-wise comparisons indicated that infants in the *Voice only* condition smiled significantly less than infants in the *Face only* condition ($p < .01$) and marginally less than the infants in the *Face plus Voice* condition ($p = .051$). The period main effect also reached significance, $F(2, 66) = 5.50$, $p < .01$. Across conditions, infants smiled significantly less in the still-face period than in the preceding and proceeding normal interaction period, $F(1, 33) = 9.90$, $p < .01$. Moreover, the interaction effect was significant, $F(4, 66) = 4.07$, $p < .01$, indicating that the mean duration of infant smiling during different interaction periods depended on condition. LSD pair-wise comparisons for each interaction period revealed that during P1 infants mean duration of smile was significantly higher in the *Face only* than in the *Face plus Voice* and *Voice only* condition. During P2, infants in the *Voice only* condition smiled significantly less long than the infants in the *Face plus Voice* and *Face only* condition. No other comparison reached significance.

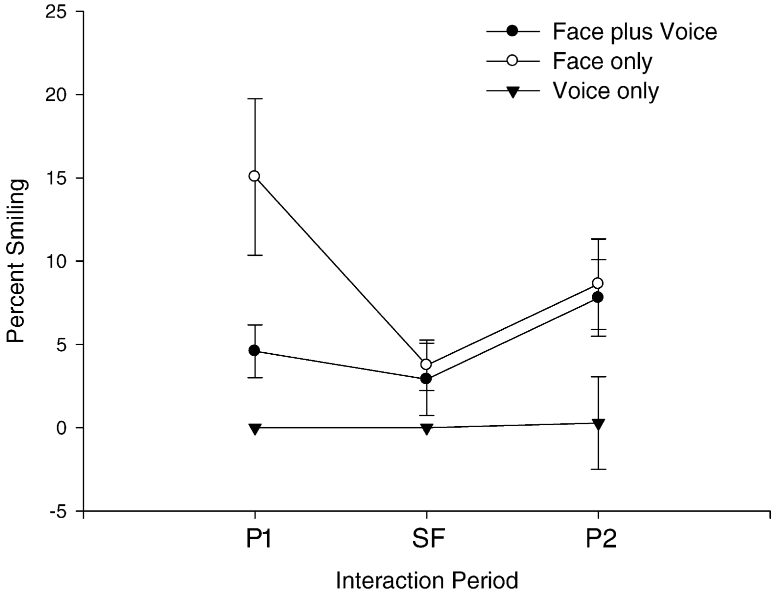

Fig. 2. Percent of smiling and standard error as a function of condition and interaction period.

Analogous analyses for *Positive Vocalization* and *Negative Vocalization* yielded no significant main or interaction effects (all p's > .05), suggesting that infants' mean duration engaged in positive and negative vocalization did not vary as a function of condition or interaction period.

4. Discussion

We assessed the contribution of contingent facial and vocal information in producing the still-face effect in 4-month-old infants. We utilized a paradigm whereby infants received facial and vocal stimulation during a normal mother–infant interaction (*Face plus Voice*), received facial but no vocal stimulation (*Face only*), or received only vocal stimulation when the mother interacted with the infant from behind a curtain (*Voice only*). In contrast to prior studies (Gusella et al., 1988) there was no conflict between facial and vocal information. Based on research showing that infants use mothers' positive vocal cues in social referencing, even when these are not accompanied by facial cues (e.g., Mumme et al., 1996; Vaish & Striano, 2004) we expected that infants would manifest a still-face response in the *Voice only* condition. This hypothesis was not supported. Rather, the current findings replicate the original findings of Gusella et al. in that the voice did not contribute to a still-face effect. These findings provide support that the still-face effect is just that—it is due to a still-face and not to a still-voice.

This finding leads to the question of why vocal information does not contribute to the still-face effect in 4-month-olds in dyadic face-to-face situations, but seems to be fundamental to social referencing by the end of the first year (e.g., Mumme et al., 1996; Vaish & Striano, 2004). The face provides key information about the referential nature of others' behaviors and emotions and assists humans in establishing the meaning of social cues (see Moses, Baldwin, Rosicky, & Tidball, 2001; Striano & Rochat, 2000). Thus, sensitivity to eye contact might be one explanation for the lack of still-face effect in the *Voice only* condition. That is, because infants did not have eye contact with their mothers in this condition, they had no access to the emotional cues conveyed by her face. However, the eye contact interpretation cannot be the entire explanation for at least two reasons. First, from birth, infants are sensitive to eye contact (e.g., Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Massaccesi, & Simion, 2002). However, there is no reported still-face effect at birth, suggesting that social experience may be necessary for human infants to develop social expectations. Second, infants between 3 and 9 months of age manifest a robust still-face effect even if the adult is not looking at them (see Delgado, Messinger, & Yale, 2002; Striano, 2004).

Infants in the *Face plus Voice* and *Face only* condition had contingent facial cues disrupted during the SF period—facial cues to which infants in the *Voice only* condition had no access. A particular visual cue alone or in concert with vocal cues might be essential for the still-face effect in 4-month-olds. This idea is in line with theories suggesting that the recognition and discrimination of emotional expressions is enhanced with multimodally presented information (face *and* voice) compared to information presented from only one modality (face *or* voice) (see Walker-Andrews, 1997; also Walker-Andrews & Lennon, 1991). Furthermore, it is possible that smiling contributed to the still-face response. Infants in the *Face plus Voice* and *Face only* conditions saw their mother's smile abruptly disappear from the P1 to the still-face period. The results showed that infants' attention to the mother's face declined significantly between these two interaction periods accompanied by a drop in positive affect. Infants in the *Voice only* condition exhibited relatively little positive affect in all three interaction periods, indicating that only hearing a mother's positive interactive voice is not enough to elicit smiles in infants. Thus, the still-face reaction might reflect a sensitivity to an interaction partner's smiling expression. This hypothesis is corroborated by research that found that infants look reliably longer to smiling than to neutral expressions (e.g., Kuchuk, Vibbert, & Bornstein, 1986; Striano, Brennan, & Vanman, 2002). However, research has also shown that maintaining a positive facial expression during the still-face period does not play a strong role in modulating infants' still-face reaction (e.g., D'Entremont & Muir, 1997; Rochat, Striano, & Blatt, 2002). These findings have led to the conclusion that the loss of interpersonal contingency is a major contributor to the still-face. If this is the case, the current study shows it is a loss of facial contingency and not vocal contingency.

The observed difference in still-face effect between the *Face plus Voice*, *Face only* and the *Voice only* condition might also lie in infants' sensitivity to facial movement. In both the *Face plus Voice* and *Face only* condition there was a loss of the interaction partners' facial movement during the still-face period. Infants might simply react to the sudden absence of facial movement with decreased visual attention and positive affect. Research has shown that infants are sensitive to movement and visually prefer a moving over a static stimulus (e.g., Dannemiller & Freedland, 1989; Hicks & Richards, 1998; Lewis, Maurer, Burkhanpurkar, & Anvari, 1996). Furthermore, Ellsworth et al. (1993) found that 3- and 6-month-olds exhibited the same still-face effect for gaze whether a person or an interactive object (a hand puppet whose internal features moved) became still-faced. The authors argue that "...infants' visual attention may have been driven primarily by movement..." (p. 68).

While we alluded to possible explanations for the observed differences in the still-face response in 4-month-olds, the question of why infants failed to exhibit a still-face effect in the *Voice only* condition when, just a few months later, they are adept at using vocal cues to guide their own behavior (Mumme et al., 1996; Vaish & Striano, 2004) remains. Future studies are needed to address these questions. For example, there is scant research relating developing dyadic skills such as social expectations in the still-face paradigm to triadic behaviors that require infants to understand someone's expression as intended for the self but referring to something else. One area for future research could be to assess infants' behavior in dyadic and triadic contexts to determine if and when there are strong relations. Another area of future research is to test infants' social expectations as a function of development. This approach would establish if learning and experience play a role in infants' understanding of the relevance of vocal cues that are not accompanied by faces. A developmental approach is also critical in teasing apart the relation between maturation and experience. For example, if 12-month-old infants rely upon vocal cues in social referencing but younger infants do not, can this development be better explained by the emergence of locomotion or developing action systems, rather than more general experience? With developing action systems such as independent locomotion, the need for information changes as does the contexts in which it is provided. Studies are needed to determine how action systems and the need for information control the channels of communication that are selected and used by infants. It would be useful to know for instance, if the significance of facial cues declines over the first year and if the importance of vocal cues increases as a function of locomotion and the need to social reference and use emotional cues when far from the caregiver (see Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein, & Witherington, 2000).

The current study tested only 4-month-olds and was limited in sample size. In addition to testing more infants, it should be assessed if older infants are more inclined to respond to a loss of contingent vocal cues in dyadic contexts, and if these are the same infants who use vocal cues in social referencing (triadic) tasks. The voice is an integral part of social skills (see Fernald, 2001) and in establishing the meaning of expressions among adults (Schirmer, Kotz, & Friederici, 2002), but it is not a determinant of the still-face response in 4-month-olds. The key is to establish in which contexts vocal and facial cues are perceived as relevant and the developmental course of these sensitivities.

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BRIEF REPORT

Coordinated affect with mothers and strangers: A longitudinal analysis of joint engagement between 5 and 9 months of age

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The coordination of affect in joint attention was assessed in a longitudinal study of 5- to 9-month-old infants as they interacted with mothers and strangers. Results showed that the coordination of affect with joint attention looks increased reliably with age. In addition, context effects were found such that joint attention looks increased while interacting with strangers but not with mothers. The study demonstrates the emergence of joint engagement before the end of the first year, and suggests that affect may play a key role in aspects of joint attention that may be unique to humans.

Joint engagement is considered a crucial part of human cognition, essential for skills such as language and theory of mind (e.g., Farroni, Mansfield, Lai, & Johnson, 2003). Although a wide range of species coordinate gaze between conspecifics and things (see Emery, 2000), in no other species is the inclination to share affect and to communicate about things by showing and offering them and by engaging in joint attention behaviour as strong as it is in humans (e.g., Tomasello, 1999). Given its potential role in human cognition, many questions have been asked about the development and function of joint engagement.

In a longitudinal study that considered the interrelationship of social-cognitive skills at monthly intervals between 9 and 15 months of age, Carpenter, Nagell, and Tomasello

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(1998) reported the onset of joint engagement at 9 months of age. In one descriptive study on joint engagement before the end of the first year, Trevarthen and Hubley (1978) reported on one infant's interactions with her mother and objects. Whereas the infant showed interest to both objects and her mother in the early months, there was little evidence of coordinating attention between the objects and her mother until the end of the first year (see also Saxon, Frick, & Columbo, 1997). Interestingly, the infant also began to exchange smiles with her mother while playing at this age.

Bakeman and Adamson (1984) observed infants between 6 and 18 months of age while playing in the home with their mother or a peer. Coordinated joint engagement increased with age in both the mother-infant and the peer-infant play sessions. At all ages, infants were much more likely to coordinate attention when playing with mothers than with peers. These findings suggest that caregivers effectively scaffold infants' joint engagement in ways that peers do not. This may be due to the infant peers' less expansive behavioural repertoire. An alternative explanation, however, is that the higher frequency of joint engagement with the mother might reflect an inclination to share attention with a more familiar social partner, and that mothers are simply more familiar to infants than are peers. Observed differences in the frequency of joint engagement toward familiar versus less familiar social partners could help to assess the function of joint engagement. For instance, if joint engagement merely reflects learning or developing attention (e.g., Corkum & Moore, 1995) we might expect the same frequency of this skill regardless of the familiarity of the interacting social partner. This is most likely not the case, given that research with young infants suggests that familiarity of the social partner affects social responding.

Bigelow (1998) tested 4 to 5-month-olds' sensitivity to the contingent responsiveness of their mother versus a stranger during a face-to-face interaction. The authors found that infants vocalised and smiled more to a stranger whose level of contingent responsiveness was similar to that of their own mother (see also Bigelow & Birch, 1999). In a study assessing 5-month-olds' sensitivity to maternal contingency, Hains and Muir (1996) found that compared to interactions with strangers, infants tended to accept brief bouts of noncontingent behaviour from their mothers, presumably because they were more familiar with her interactive style. Furthermore, 4-month-old infants engage in more vocal coordination with strangers than with their mothers when interacting in the laboratory (i.e., Jaffee, Beebe, Feldstein, Crown, & Jasnow, 2001) which suggests that young infants may be more inclined to coordinate attention with strangers.

While the ability to engage in triadic interactions is not unique to humans, the sharing of affect during these episodes may be unique. Bakeman and Adamson (1984) defined joint engagement as ''the infant is actively involved with and coordinates his or her attention to both another person and the object the person is involved with'' (p. 1281). Carpenter and colleagues (1998) used a similar definition, but neither considered positive affect accompanied by coordination of gaze. It is surprising that affect has not been considered in recent studies of joint attention—given that affect seems to be the element that makes engagement joint—and more than the mere coordination of visual attention which so many species do.

Studies by Mundy, Kasari, and Sigman (1992) are an exception. They reported that 20-month-old infants systematically displayed more positive affect (smiling) when engaged in joint attention behaviours (e.g., showing objects) than when engaged in requesting behaviour (e.g., pointing to objects). The authors concluded that a critical difference between joint attention skills and requesting skills may lie in the production of affect (see also Mundy, 1995). A study by Adamson and Bakeman (1985) assessed the relationship between positive affect and attention during object play with mothers and with peers. Starting at 9 months of age affective expressions were reliably more likely to occur when infants were in coordinated joint engagement with their mothers than with their peers. Affect was also observed in episodes of passive joint engagement with mothers (i.e., noncoordinated). These observations led the authors to conclude that ''joint engagement is *not* simply an alternation of periods of object play and period of person play with affect timed to coincide with moments of the latter'' (p. 591).

The current study assessed the coordination of smiling with visual joint engagement production in a group of 5- to 9-month-old infants observed on a longitudinal basis. This investigation is the first large-scale study to assess joint engagement before the end of the first year. Assessing the development of joint engagement before 9 months of age is critical given that those studies that suggest joint engagement begins at 9 months of age, did not consider developmental patterns *before* that age period (see Carpenter et al., 1998). The study is also unique in its consideration of affect and joint engagement together. These two domains have never been systematically studied in a longitudinal investigation. Assessing how these skills co-emerge is critical in establishing if affect plays a unique role in human joint attention.

METHOD

Participants

A total of 77 infants participated in the study. Eight infants were excluded due to fussiness in at least one session (n = 6) and experimental error (n = 2). The final sample consisted of 69 infants (29 males and 40 females). They were seen at 5 months (M = 168.28 days, SD = 7.22), 7 months (M = 226.59 days, SD = 10.11), and at 9 months of age (M = 296.10 days, SD = 11.51). All participants were healthy and full-term, and recruited from a city hospital of a mid-size town in the east of Germany. Caregivers received a videotape of all the sessions, a small gift for the infant, and a travel allowance.

Procedure

Testing took place in a carpeted room within an area surrounded by white curtains to eliminate any possible distractions. The infant and an interaction partner sat 60 cm across from each other on the floor. Several toys (e.g., picture book, various rattles) were placed between the infant and the interaction partner. The interaction partner was either the infant's mother or a stranger. The order of the interaction partner was counterbalanced across infants and determined a priori. Infants and interaction partners played with the toys during a 2 min freeplay session.[1]

During the mother-infant interaction session, the mother engaged the infant in freeplay with the toys while the stranger sat unobtrusively on the floor behind the infant and, if needed, held the infant in a way that it did not restrict the infant's toy exploration. The position of the mother and stranger were reversed in the stranger-infant play session. The

[1] The 2 min freeplay sessions were embedded within a battery of tasks that lasted approximately 20 min in total. These tasks are not considered in the current study.

interaction partners were instructed to engage with the infant and the toys in normal play. Play sessions were filmed with four digital video cameras. One camera captured a front close-up view of the infant, another a profile view of the infant and the interaction partner, a third the interaction partner, the infant, and the toys, and a fourth camera the top view of the entire play setting.

The familiar interaction partner was always the infant's mother. In order for the stranger to be a novel person to the infant, different strangers were used across visits.[2] A total of six strangers were used as unfamiliar interaction partners. Preliminary analyses indicated that type of stranger did not influence infants' performance (*JE-looks* and *JE-looks with smile*: all ps > .1). The play behaviour of the mothers and the strangers was analysed to examine if they behaved similarly during the play sessions. The results revealed that mothers and strangers did not significantly differ in the time they manipulated the toys ($t = 0.23$, $p > .05$), smiled at the infant ($t = -1.27$, $p > .05$), and talk to the infant ($t = 0.66$, $p > .05$).

Dependent variables

The 2 min freeplay sessions were coded from videotapes by a trained coder blind to the hypotheses of the study. The following behaviours were coded.

Joint engagement looks (JE-looks). Infants' gaze from a toy to the interaction partner's face and back to the same toy were counted as *JE-looks*. Infants' looks back to a different toy were not coded as *JE-looks*. Any looks to the interaction partner in response to her speaking or moving were not counted. Infants received a ''1'' if they displayed the behaviour at least once during the 2 min play session. Infants who did not display the behaviour received a ''0''.

Joint engagement looks with smile (JE-looks with smile). Infants who received a ''1'' in the above measure, were scored again to determine if the *JE-looks* were accompanied by a smile. A smile was defined as cheeks raised and at least one corner of the mouth turned up while looking at the interaction partner. Only infant-initiated smiles during *JE-looks* were counted. Smiles in response to the interaction partner's smiles were not counted. Infants received a ''1'' if at least one *JE-look* was accompanied with a smile. Infants who never smiled during *JE-looks* received a ''0''.[3]

To assess intercoder reliability, a second, naive coder scored a random 20% of the freeplay sessions. The agreement between the two observers was Cohen's kappa .94 for the *JE-looks* and Cohen's kappa .73 for *JE-looks with smile*.

[2] Two infants played with the same stranger in two of their visits.

[3] *JE-looks* and *JE-looks with smile* are not mutually exclusive measures. Receiving a ''1'' for *JE-looks* indicated that the infant displayed one or more joint engagement look regardless of positive affect. Receiving a ''1'' for *JE-looks with smile* indicated that at least one of the infant's *JE-looks* was accompanied by a smile.

RESULTS

JE-looks

Table 1 displays the frequency of *JE-looks* and *JE-looks with smile* for the mother and stranger condition. Separate nonparametric tests for repeated samples with binary measures were conducted to assess age effects for both social partners (mother and stranger). A Cochran Q test revealed that there were no systematic differences in the number of infants who displayed *JE-looks* while playing with their mother at 5, 7, and 9 months of age $Q(2) = 4.68$, $p > .05$. However, for the stranger condition, there was a reliable difference in the number of infants who displayed *JE-looks* across the different ages, $Q(2) = 32.01$, $p < .001$. Follow-up McNemar (Siegel & Castellan, 1988) chi-square pairwise comparisons indicated that the number of infants who coordinated attention with strangers at both 7 and 9 months of age was significantly higher than the number of infants who engaged in this behaviour at 5 months of age ($p < .001$ in both cases). The number of infants who coordinated attention with strangers at 7 and 9 months of age did not differ (McNemar, $p > .05$).

Additional McNemar chi-square tests revealed that at both 7 and 9 months of age, significantly more infants coordinated attention with strangers than with mothers (7-month-olds: $p < .01$; 9-month-olds: $p < .001$). The frequency of *JE-looks* between the mother and stranger condition did not differ for infants at 5 months of age (McNemar, $p > .05$). This result points to a differentiation in the production of *JE-looks* with mothers versus strangers by 7 months of age.

JE-looks with Smile

Table 1 shows the number and percentage of infants who accompanied at least one *JE-look* with a smile to the mother and stranger. For the mother condition, a Cochran Q test revealed a reliable age effect in the number of infants that displayed *JE-looks with smile*,

TABLE 1
Frequency (and percentage of total infants) of each target behaviour in the mother and stranger condition at 5, 7, and 9 months

	Age (months)					
	5		*7*		*9*	
Behaviour and condition	*f*	*(%)*	*f*	*(%)*	*f*	*(%)*
JE-looks						
Mother	20	(28.99)	31	(44.93)	29	(42.03)
Stranger	21	(30.43)	48	(69.57)	52	(75.36)
JE-looks with smile						
Mother	2	(2.90)	9	(13.04)	12	(17.39)
Stranger	3	(4.35)	8	(11.59)	24	(34.78)

Note: Frequencies (f) constitute numbers of infants who displayed behaviours at least once during the 2 min play session. Percentages are based on 69 infants.

Q(2) = 8.32, $p < .02$. Follow-up McNemar chi-square pairwise comparisons indicated that the number of infants who accompanied at least one *JE-look* with a smile was significantly higher at 9 months of age compared to 5 months of age ($p < .01$), and marginally higher at 7 months compared to 5 months of age ($p = .06$). There were no other significant differences.

The number of infants who smiled while coordinating their attention with strangers was significantly higher at 9 months of age than at 5 and 7 months of age ($p < .001$ and $p < .01$ respectively). In addition, 9-month-olds were more likely to accompany their *JE-looks* with smiles when playing with strangers than with mothers (McNemar, $p < .005$). There were no other significant differences. Together, these analyses reveal that the number of infants who accompanied joint engagement looks with positive affect increased with age regardless of social partner. Also, at 9 months of age the number of infants who displayed *JE-looks with smile* was significantly higher in the stranger than in the mother condition.

The general finding that *JE-looks with smile* increased similarly in the mother and stranger condition was corroborated with a binary logistic regression model with repeated measures. The analyses revealed that *age* (5-, 7-, and 9-month-olds) had a significant effect (Wald $\chi^2(1) = 9.92$, $p < .01$; $e^{\beta} = 1.69$) on *JE-looks with smile*.[4] Thus, with development, infants increasingly coordinated joint engagement behaviour with smiles. There were no other main effects or interactions, suggesting that this pattern of results was similar for both the mother and stranger as interaction partner.

DISCUSSION

In a longitudinal study that assessed infants between 5 and 9 months of age, we investigated how infants coordinate affect with joint (triadic) attention. Although visual joint engagement has been documented in infants older than 9 months of age (i.e., Carpenter et al., 1998), no large-scale longitudinal study has considered the developmental emergence of joint engagement or how affect and visual joint engagement are integrated over development. In addition to asking these fundamental questions, the study assessed whether the integration of joint engagement and affect followed a similar pattern when infants interacted with mothers versus strangers.

The developmental effects of the current study point to a much earlier and more gradual emergence of joint engagement than has been proposed by other researchers (see also Striano & Bertin, in press; Striano & Rochat, 1999). Although the results show an increased coordination of affect and attention by the end of the first year, the transition to joint engagement was not as abrupt as suggested by some researchers (i.e., Tomasello, 1995, ''9-month-revolution''). In fact, many infants in the current study were coordinating visual attention with mothers and strangers by 5–7 months of age.

The study revealed that in relation to the interaction partner, the number of infants who engaged in coordinated attention changed with age only in the stranger condition. In addition, by 7 months of age infants were more likely to coordinate looks with strangers than with mothers. Thus, our hypothesis that infants would engage in more

[4] e^{β} is the predicted change of odds for a unit increase in the covariate (Tabachnick & Fidell, 2001). In the current study, this means that for every 1 month increase in age, it will be 1.69 more likely than in the previous month, that *JE-looks with smile* occur than not.

coordination (as indexed by *JE-looks*) with strangers than mothers was supported. The findings with the interaction partner suggest that context may play a key role in the establishment of joint attention. The increased *JE-looks* with strangers compared to mothers is in line with prior research with younger infants showing more coordination with strangers than mothers (e.g., Jaffe et al., 2001). It is important to note that, although there were no differences in this general pattern of results as a function of the different unfamiliar interaction partners, the meaning of this effect will rely upon further investigations. For instance, context effects or the quality of a stranger's interactive style in general and also relative to the infant's prior experience may play a key role (see also Bigelow, 1998).

The pattern of results was different for the coordination of joint engagement and affect. In general, the study revealed that with development, infants are more likely to coordinate their joint engagement behaviour with positive affect. The number of infants who accompanied joint engagement looks with positive affect increased with age regardless of the interaction partner. Only by 9 months of age, the number of infants who coordinated *JE-looks* and *JE-looks with smile* was significantly higher in the stranger than in the mother condition. The coordination of affect and joint engagement points to a possible shift in the meaning of this skill by the end of the first year. In general, the findings are in line with Hobson's ideas that: ''Jointness comes with being moved just enough to sense the psychological orientation of the other in oneself, but as the other's. This happens through intersubjective engagement that is emotional in source and emotional in quality'' (Hobson, in press). Future studies will be needed to determine which factors underlie this developmental shift given that infants coordinate affect in dyadic contexts much earlier (see Murray & Trevarthen, 1986; Nadel, Carchon, Kervella, Marcelli, & Reserbat-Plantey, 1999; Rochat, Querido, & Striano, 1999). However, the increase of *JE-looks* at 7 and 9 months of age and coordination of *JE-looks* with smiles by 9 months of age with strangers compared to mothers suggests that this behaviour is not the result of associative learning mechanisms.

Differences in the coordination of joint engagement and smiles as a function of the interaction partner may be revealing in this regard. The current pattern of results is different from that of Bakeman and Adamson (1984) who compared the coordination of affect with mothers versus peers and found greater coordination with the mother. Again, these differences could point to potential context effects given that the adult strangers in the current study likely had a much more expansive social repertoire than infant peers. Future studies will be needed to manipulate and bias infants' joint engagement and affect toward strangers, for instance by having infants interact with an unfriendly or noncontingent stranger.

The ability to coordinate attention with another person is a necessary precursor for many aspects of human cultural learning. For example, understanding the reference of another's gaze is necessary for social referencing, language learning (Baldwin, 1993, 1995; Morales, Mundy, & Rojas, 1998; Mundy & Gomes, 1998), and imitative learning (e.g., Brooks & Meltzoff, 2002). However, while such skills may be necessary prerequisites to uniquely human capacities, coordinating visual attention is certainly not a unique human capacity (see Emery, 2000, for a review). The accompaniment of affect with the coordination of gaze, however, is only observed in humans. The timing and coordination of smiling and joint engagement may be the key to the developmental social-cognitive transition reported by the end of the first year.

The current findings show the emergence of joint engagement before the end of the first year. In addition, these results suggest that assessing early development may be key in pointing to meaningful transitions in social-cognitive competencies across early ontogeny. Along these lines, the current findings are consistent with Mundy and colleagues (e.g., Kasari, Sigman, Mundy, & Yirmiya, 1990; Mundy et al., 1992; Mundy & Sigman, 1989) who propose that the initiation of joint attention behaviours *accompanied* by positive affect may not be the same as other types of joint attention behaviours, such as gaze following or requesting, which do not necessarily consist of an affective component. When one takes affect into account, as was done in the current study, more clear developmental patterns may be observed than in prior studies (e.g., Carpenter et al., 1998). The coordination of positive affect with gaze was not considered by Carpenter and colleagues (1998) and might have contributed to the relatedness among many of the joint attentional skills considered by these authors. That is, it is conceivable that none of these joint attention tasks may have been indexing the sharing of affect that makes coordinated attention truly joint, or a meaningful shared experience (Hobson, 2002, in press).

A consideration of the interplay between affect and triadic social skills over the course of ontogeny is a fruitful avenue for future research. In addition, it will be important to assess mechanisms of developmental change. That is, many infants in the current study were coordinating visual attention with mothers and strangers by 5 months of age, but only a few infants at this age coordinated affect with visual joint engagement. The question remains whether the 5-month-olds in the current study simply could not coordinate triadic visual attention and affect due to possible memory or attention constraints (see Ruff & Rothbart, 1996), or whether they did not engage in such behaviour because they lacked an awareness of intentional relations. Clearly, further studies are needed to assess the meaning and the developmental course of various joint attention tasks, such as attention following and social referencing. The initiation of coordinated attention with positive affect may index the active attempt by the human infant to share emotional states with others about things in the world. As suggested by the current findings and by Hobson (in press) affect may be what puts ''jointness'' into joint engagement.

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Running Head: INFANTS' OBJECT PROCESSING IN SOCIAL CONTEXTS

The Influence of Social Context on Infants' Object Processing

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Abstract

In two experiments we systematically manipulated social-interactional factors within triadic structures to examine their influence on 9- and 12-month-old infants' object processing. Infants interacted with an adult in either a joint attention episode in which the adult coordinated attention between the infant and the object, or in one of two non-joint attention episodes where the social partner focused only on the infant or only on the object. Object processing was tested in a subsequent novelty preference task. Results revealed that while 9-month-olds' object processing was negatively affected in conditions were the adult engaged in infant-directed looks, 12-month-olds' object processing was more robust to manipulations of the social-interactional factors. Thus, object processing and learning does not take place in a vacuum, but is sensitive to social-interactional factors.

Key Words: Triadic Interaction

Joint Attention

Object Processing

Social Context

Infancy

The Influence of Social Context on Infants' Object Processing

Over the past few decades, we have made considerable progress in our understanding of how infants perceive and interpret the social and physical world (for reviews see Bremner, 2004; Rochat, 1999). These two research fields have, independently, added to our knowledge of infants' social and perceptual understanding and development. However, there is little research combining these two areas of investigation. Past research has largely ignored the question of how social-environmental factors influence infants' perception of the object world. In the current study, we examined infants' visual object processing within the triadic relation of self, other, and object.

Prior research has revealed that social-environmental factors have a dramatic influence on infants' behavior. For example, infants as young as 2 months of age reliably gaze and smile less toward an unresponsive compared to a reciprocating adult (e.g., Striano & Stahl, 2005; Tronick, Als, Adamson, Wise, & Brazelton, 1978). Moreover, social-environmental factors influence a variety of social-cognitive skills such as declarative gestures (e.g., Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004), gaze following (e.g., Flom & Pick, 2005), language learning (e.g., Tomasello & Todd, 1983; see also Baldwin, 1995), and play skills (e.g., Bigelow, MacLean, & Proctor, 2004). Together, these findings suggest that infants are sensitive and attentive to the social signals of others and use this information to adjust their behavior.

While many studies indicate that infants modify their own behavior according to the social signals they receive, little is known about the influence of the social partner's behavior on infants' processing of the object world. There are but a few exceptions. For example, Miceli and her colleagues found that the type of maternal behavior during a mother-infant toy play session was associated with 4-month-old infants' level of information processing during a separate paired-comparison novelty preference task (Miceli, Whitman, Borkowski, Brautgart-Rieker, & Mitchell, 1998). Specifically, infants whose mothers were less involved during the toy play session (e.g., less verbal and visual encouragement of infant's attention), were more likely to prefer the novel stimulus during the visual discrimination task—the type of visual preference that is associated with superior information processing.

Itakura (2001) tested older infants (9-13-month-olds) to assess whether social and non-social events led to differential behavior on subsequent visual preference tasks. In this study, infants observed either the mother point to one of two line drawings (social event) or saw one of the line drawings blink (non-social event). In both conditions infants looked longer to the stimulus-enhanced drawing (i.e., the one that was pointed at or blinked). However, when the line drawings were presented alone (without pointing or blinking), only the infants who were in the social condition showed a significant difference in their looking preference, in that they looked longer at the drawing that was pointed at versus the one to which the mother did not point. Thus, looking behavior was influenced by the preceding social and non-social event.

Recently, Reid and Striano (2005) assessed the effects of eye gaze cues on 4-month-olds' attention and object processing. In a computerized joint attention paradigm an adult gazed toward one of two objects. When infants were tested with the same objects alone, they looked reliably *less* to the object to which the adult had directed her gaze. This suggests that an adult's gaze guides infants' attention and facilitates information processing in the cued location. Using the same basic procedure, albeit modified for measuring event-related potential (ERP), 4-month-olds' object processing at the neural level was assessed (Reid, Striano, Kaufman, & Johnson, 2004). The results of this study corroborated the behavioral findings. In particular, the cued object (object adult gazed at) elicited neural activities indicative of familiarity with the object. Thus, the cued object was processed more deeply than the uncued object. In a further experiment involving an interactive-live ERP paradigm, an adult gazed either at the infant's face and then to a novel object presented on a computer screen (joint-attention context), or only to the novel object (non-joint attention context) (Striano, Reid, & Hoehl, in press). Results revealed that the neural correlates indexing attentional processes were enhanced when 9-month-old infants engaged in joint attention compared to non-joint attention interactions. Thus, within joint attention episodes, attentional resources were focused towards the novel object which may lead to deeper processing and more effective learning of the new information. Together, these studies indicate that social-environmental factors not only influence infants' own behavior, but also infants' processing of the physical world.

In the current study we further examined the influence of social context on infants' object processing by systematically manipulating the social-interactional factors in the triadic structure. Similar to previous studies (Reid & Striano, 2005; Reid et al., 2004; Striano et al., in press), infants either participated in a joint attention condition in which the adult social partner alternated her gaze between the infant and the object, or in different types of non-joint attention conditions where the adult focused only on the infant, only on the object, or was not present. However, the current study is different and novel in several aspects. First, unlike previous studies, where either the object or both the object and the social partner were presented on a computer screen, the object as well as the social partner were live in the current study. Infants encounter live interactions on a daily basis, whereas fully or partly computer-based interactions are unnatural and likely not often occurring in the infant's world. Thus, testing infants in live triadic interactions will inform us whether or not the ongoing interactive behavior of the social partner influences infants' perceptual processing of novel objects. Second, the examination time of the familiarization object was much longer compared to earlier studies. That is, object processing was tested after infants examined the familiarization object for an extended amount of time, whereas earlier studies examined object processing immediately after initial attention was directed toward the object. Thus, instead of investigating socially induced attention-getting effects on novel information processing, we explored the effects of prolonged object examination within various social contexts. Third, given the prolonged familiarization phase, the adult social partner gazed at the infant and/or the object several times during the familiarization phase, whereas in previous studies the adult social partner looked at the infant and the object only once before the test. Thus, infants had the chance to observe the social partner's behavior toward him/herself and the object several times. It is conceivable that observing the adults' interactive behavior on several occasions influences infants' basic information processing differently than when only one short look toward infant and object is exerted by the adult. In general, the influence of the social partner's behavior on infants' object processing was examined within a live triadic setting where infants had enough time to process the object as well as the nature of the social signals defining the interaction.

Infants' processing of the object was tested in a subsequent paired-comparison recognition test in which the familiar object was simultaneously presented with a novel object. As is commonly assumed in this paradigm, a significant novelty preference is indicative of the infant's ability to discriminate between the stimuli—an ability which rests upon effective stimulus processing during familiarization (e.g., Colombo, 1993; Hunter & Ames, 1988).

Joint attention, which involves both social partners' awareness of the other's focus to an external, mutually interesting event, is a natural behavior likely to be displayed during object-incorporated interactions (Bakeman & Adamson, 1984). By the end of the first year, infants commonly exhibit such joint engagement episodes (e.g., Carpenter, Nagell, & Tomasello, 1998; Striano & Bertin, 2005). In Experiment 1, we examined whether 9- and 12-month-old infants' ability to process object information is differentially affected by social situations in which an adult engages in joint attention behavior, compared to non-social situations in which no social partner is present.

Experiment 1

Method

Participants. Participants were 32 nine-month-olds (18 females, 14 males, mean age = 274.91 days, *SD* = 5.53) and 32 twelve-month-olds (15 females, 17 males, mean age = 364.19 days, *SD* = 4.65) from a German city. An additional 11 participants started the experiment but were excluded from the final sample for crying (*n* = 5; 3 9-month-olds, 2 12-month-olds), for familiarity with one of the objects (*n* = 3; 2 9-month-olds, 1 12-month-old), or for grabbing one of the objects (*n* = 3, 12-month-olds). All infants were recruited from a database consisting of names of infants whose caregivers had volunteered to participate in studies of child development.

Apparatus and Stimuli. Infants were tested in a quiet room in an infant laboratory at the research institute. Infants sat at a table on their parents' lap facing the experimenter (E1), who sat 70 cm across from them. During the familiarization phase, one object was placed midway between the infant and E1 approximately 40° to the right or left of the infant. During the test phase, the familiar object was paired with a novel object which was placed at an equivalent distance from the infant and opposite the familiar object. Infants' gaze direction and duration were recorded with a video camera located behind E1. A white screen was lowered from the ceiling to block the infant's view while E1 placed and rearranged the objects on the table. A second experimenter (E2), positioned out of the infant's view, monitored the infant's gaze and signaled to E1 when the various phases of the experiment started and ended. A second video camera, located behind the infant, recorded E1's behavior.

The objects used in this and the following experiment were stuffed animal toys (a turtle and a dolphin) roughly equal in size and colorfulness. To counteract any *a priori* preference for a particular object, the objects that served as the familiarization and novel test objects were counterbalanced. That is, the turtle and dolphin were equally often the familiarization and test object within each condition.

Procedure. The experimental session began when the screen was raised to reveal the familiarization object (shielded from the infant's view with a piece of cardboard) and E1. After eye contact with the infant was established, E1 removed the cardboard, and with a positive facial expression and phrases such as "oh nice", encouraged the infant to look at the familiarization object. The right-left positioning of the familiarization object was counterbalanced across infants. E2 monitored when the infant looked at and away from the familiarization object and pressed a computer key to manipulate the computer's timer accordingly. Once the infant accumulated 20 s total looking time toward the familiarization object, the screen was lowered. Immediately after the familiarization phase, infants were tested on two 10-s trials in which the familiar object was paired with a novel object. The right-left positioning of the novel object on the first test trial was counterbalanced across participants (which also counterbalanced the position of the familiarization object during the test trial). The position of the novel object was reversed on the second test trial. During the test trials, E1 hid underneath the table and was not visible to the infant[1].

Infants were randomly assigned to either the *Joint Attention* or *No Social Partner* condition. The two conditions differed only in the nature of the familiarization phase. In the *Joint Attention* condition, E1 looked alternately at the infant's face and diagonally down to the familiarization object. The frequency of E1's head movement (object-infant), as well as the amount of positive vocalization was held constant within and across the 9- and 12-month-olds' *Joint Attention* condition. The *No Social Partner* condition represented a condition in which infants' object encoding was tested without any social-interactional factors. That is, only the familiarization object was visible during familiarization and infants were never exposed to E1. Infants had to look at the familiarization object for 20 seconds in both the *Joint Attention* and *No Social Partner* condition before moving to the test phase.

In order to be included in the *Joint Attention* condition, infants needed to exhibit at least one joint attention look during familiarization (as well as accumulating 20-s of looking time to the familiarization object). A joint attention look was defined as: Infant's gaze from the familiarization object to E1 and back to the familiarization object, or infant's gaze from E1 to the familiarization object and back to E1 (Mean frequency of joint attention looks per minute: 9-month-olds: 6.13 (SD = 4.64); 12-month-olds: 4.28 (SD = 1.82); $p > .05$). Such overt infant behavior toward E1 was required to ensure that infants were aware of the social interaction and excluded infants who merely focused on the object for one long 20-s look or never looked at E1 during the familiarization (see also Tomasello & Farrar, 1985, for a similar criterion).

The primary dependent measure was infants' looking time toward the familiar and novel object during the test trials. Looking time was coded from video records by an experimenter who was blind to the study's hypotheses and infants' group assignment. The test performance of 20 randomly chosen participants (each 10 9- and 12-month-olds) was coded by another naïve experimenter to examine inter-observer reliability. The average Pearson correlation between the two observers was 0.95 ($SE = .03$).

Results Experiment 1

Preliminary analyses revealed that infants' gender and the type of familiarization object did not significantly affect their preference during the test trials. Thus, the data were collapsed over these variables in subsequent analyses. As is customary in perceptual studies employing the paired-comparison novelty preference paradigm, we computed a novelty preference score (e.g., Bertin & Bhatt, 2001; Frick, Colombo & Allen, 2000; Quinn, Burke & Rush, 1993) to examine infants' performance during the test trials. This score was derived by dividing the duration of looking toward the novel object during the two test trials by the total duration of looking toward both objects during the test and multiplying this proportion by 100 to get a percentage preference score.

Figure 1 displays infants' mean novelty preference scores during the test trials. An age (9- and 12-month-olds) x condition (Joint Attention and No Social Partner) ANOVA revealed a significant interaction effect, $F(1, 60) = 4.22$, $p < .05$. Follow up t-tests indicated that 9-month-olds' mean novelty preference score in the *Joint Attention* condition was significantly lower than their novelty preference score in the *No Social Partner* condition ($p < .02$; two-tailed), as well as 12-month-olds' novelty preference score in the *Joint Attention* condition ($p < .03$; two-tailed).

The mean novelty preference scores were also compared to the 50% chance level. Mean preference scores around 50% indicate no preference for either the familiar or the novel object, whereas scores greater than 50% indicate a preference for the novel object. The analyses revealed that 9-month-olds' novelty preference score was significantly higher than chance in the *No Social Partner* condition ($M = 63.81$; $SE = 3.74$; $t(15) = 3.70$, $p < .01$, two-tailed), but not in the *Joint Attention* condition ($M = 52.08$; $SE = 2.72$; $t(15) = .76$, $p > .1$, two-tailed). The preference score of the 12-month-olds was significantly different from chance in both the *No Social Partner* and the *Joint Attention* condition ($M = 59.85$; $SE = 3.98$; $t(15) = 2.47$, $p < .03$, two-tailed; $M = 62.50$; $SE = 3.44$; $t(15) = 3.64$, $p < .01$, two-tailed, respectively).

Discussion Experiment 1

Experiment 1 revealed that the effect of social context during the familiarization phase on visual preference during the test phase was different for 9- than 12-month-olds. While 12-month-olds revealed novelty preference scores indicative of full stimulus processing in both the *Joint Attention* and *No Social Partner* condition, 9-month-olds' scores were suggestive of such behavior only in the non-social encoding context. Surprisingly, joint attention episodes were social contexts that impeded 9-month-olds' object encoding. In Experiment 2, we further manipulated the triadic interaction between infant, object, and the social partner.

Experiment 2

Joint attention looks entail both a look directed toward the infant as well as one directed toward the object. To further investigate which of these looks (to infant or to object) influenced 9-month-old infants' object encoding, we further manipulated the triadic episode. In particular, we created two non-joint attention conditions in which the social partner either looked only at the infant or only at the object. If 9-month-olds' poor performance in the *Joint Attention* condition was an effect created jointly by the infant- and object-directed looks, then they might do better if the social partner engages only in one type of look. If, however, one of the looks was more pivotal than the other, we should expect performance differences in the two conditions. Twelve-month-old infants were also included in this experiment to examine whether at this age, object processing was robust to manipulations of the interactional social structure.

Method

Participants. Participants were 32 nine-month-olds (13 females, 19 males, mean age = 275.34 days, *SD* = 6.85) and 32 twelvemonth-olds (17 females, 15 males, mean age = 365.81 days, *SD* = 5.71). An additional 6 participants started the experiment but were excluded from the final sample for crying (*n* = 1; 12-month-old), for never looking at the experimenter during familiarization (*n* = 2; each 1 9- and 12-month-old), for familiarity with one of the objects (*n* = 1; 9-month-old), for grabbing one of the objects (*n* = 1; 9-month-old), or for failing to sample both objects during test trials (*n* = 1; 12-month-old). Infants were recruited in the same manner as those in Experiment 1.

Apparatus and Stimuli. The apparatus and stimuli used were identical to those used in Experiment 1.

Procedure. The procedure was analogous to Experiment 1 except that in Experiment 2 there was no *Joint Attention* and *No Social Partner* condition. Instead, infants were randomly assigned to either the *Object Only* or *Infant Only* condition. In the *Object Only* condition, E1 looked alternately at the familiarization object and diagonally up at a spot behind the infant and midway between the infant's head and the ceiling. In the *Infant Only* condition, E1 looked alternately at the infant's face and diagonally up at the above described spot. Thus, compared to the *Joint Attention* condition of Experiment 1 (where E1 looked both at the infant *and* at the object), E1 never looked at the infant in the *Object Only* condition and never at the familiarization object in the *Infant Only* condition in Experiment 2. As in Experiment 1, infants needed to gaze at least once from the familiarization object to E1 and back to the familiarization object in short succession, or from E1 to the familiarization object and back to E1 in order to be included in the study (Mean frequency of looks per minute: 9-month-olds: *Object Only*: 4.09 (SD = 2.32), *Infant Only*: 3.20 (SD = 1.84);12-month-olds: *Object Only*: 3.58 (SD = 1.56), *Infant Only* : 3.67 (SD = 2.04) . There were no differences in the frequency infants exhibited such looks across age group or condition ($p > .1$). Like in the previous experiment, infants needed to accumulate 20 s of looking time to the familiarization object in both the *Object Only* and *Infant Only* condition. The completion of the looking criterion marked the end of the familiarization phase.

Infants' looking behavior during the test trials was coded as in Experiment 1. The test performance of 20 (each 10 9- and 12-month-olds) randomly chosen participants was coded by another naïve experimenter. The average Pearson correlation between the two observers was 0.96 (*SE* = .02).

Results Experiment 2

Preliminary analyses revealed that infants' gender and the type of familiarization object did not significantly affect their preference during the test trials. Thus, the data were collapsed over these variables in subsequent analyses. Mean novelty preference scores are presented in Figure 1. An age (9- and 12-month-olds) x condition (Object Only and Infant Only) ANOVA revealed only a marginally significant condition effect ($F(1, 60) = 3.55$, $p = .064$). Figure 1 suggests that infants response to novelty were generally stronger in the *Object Only* than the *Infant Only* condition.

To better understand infants' performance within an age group, we combined the data from Experiment 1 and 2 and examined 9- and 12-month-olds separately. A one-way ANOVA including all four conditions (*Joint Attention, Object Only, Infant Only, No Social Partner*) revealed a significant condition effect for 9-, but not 12-month-olds ($F(3, 60) = 4.38$, $p < .01$; $F(3, 60) = .57$, $p > .1$, respectively). Difference pairwise comparisons (LSD) for the 9-month-olds indicated that the mean novelty preference score in the *No Social Partner* condition was significantly higher than the preference scores in the *Joint Attention* and *Infant Only* conditions ($p < .03$; $p < .01$, respectively). Further, the novelty preference score of the *Object Only* condition was significantly higher than the preference score of the *Infant Only* condition ($p < .02$). The analysis again the 50% chance level revealed that 9-month-olds' preference score in the *Object Only* condition was indicative of a significant response to novelty during the test phase ($M = 59.55$; $SE = 3.18$; $t(15) = 3.00$, $p < .05$, two-tailed). While no condition differences were revealed for 12-month-old infants, the comparison against chance (Experiment 1) revealed that they looked significantly longer to the novel than the familiar object in the *Joint Attention* and the *No Social Partner* condition (Experiment 2: Marginal novelty preference in the O*bject Only* condition, $p = .079$, two-tailed).

Discussion Experiment 2

Infants' performance during the test phase suggests that, at least for 9-month-olds, E1's infant-directed looks during the familiarization phase (*Joint Attention* and *Infant Only* condition) influenced infants' object processing negatively (as evidenced by their chance-level performance during the test phase). While 12-month-olds' performance was not influenced differentially by E1's behavior, their high, albeit not significant, novelty preference scores in the *Object Only* and *Infant Only* condition may point to incomplete or disrupted object processing during the familiarization phase. Although 12-month-olds novelty preference scores in the *Joint Attention* and *No Social Partner* condition were significantly above the chance level (Experiment 1), we can not say with statistical certainty that they were different from their behavior in the *Object Only* and *Infant Only* conditions (Experiment 2). Together the results of this study suggest that while 9-month-olds' behavior was condition-dependent, 12-month-olds' object processing was robust to manipulations of social interactional factors.

General Discussion

The current study revealed that social-interactional factors influence infants' object processing. Depending on social context and age, different visual preference patterns emerged. It has been suggested that the type of visual preference observed during the test reflects completeness of information encoding during familiarization. That is, a novelty preference during the test phase follows complete encoding of the stimulus experienced in the familiarization phase, while a preference for the familiar or no preference for either the familiar or the novel stimulus during the test follows incomplete stimulus processing during familiarization (e.g., Hunter & Ames, 1988). Our data suggest that social-interactional factors during the familiarization phase interacted with stimulus encoding, leading to variations in visual preference during the test phase. This assumption is further supported by infants' strong novelty preference in the condition where all social factors were removed (*No Social*

Partner). However, depending on age, the various social-interactional factors influenced infants’ object processing differently.

From 9-month-olds’ novelty preference in the *No Social Partner* and *Object Only* conditions, we infer that they fully encoded the familiarization object. In these conditions, E1 was either not present or never looked at the infant. Thus, infants did not need to process social overtures directed *straight* at them. On the other hand, when E1 only looked at the infant and never at the object (*Infant Only*), or when E1 looked at the infant as part of her joint engagement looks (*Joint Attention*), object processing was negatively affected. Thus, it seems that infant-directed looks either distracted 9-month-old infants from encoding the familiarization object and/or hindered the object representation trace to fully form or consolidate. However, the current study does not provide information for testing these assumptions. On the basis of infants’ test performances, we can only make inferences about infants’ object processing during the triadic situation. Whether, and to what extent, other information is processed and remembered (e.g., information about the social partner) is subject to further investigation.

Less clear performance trends emerge from the behavioral pattern of 12-month-old infants. While only the novelty preference score of the *Joint Attention* and *No Social Partner* condition are indicative of full object processing (Experiment 1), these scores are statically not distinguishable from the preference scores obtained in the *Object Only* and *Infant Only* condition. It is possible that for 12-month-olds the task was entirely too easy or that their object processing is more robust to variations in the social partner’s behavior. However, it should be noted that 12-month-olds’ response to novelty decreased below the chance level when the social partner’s behavior was not natural during the familiarization phase (*Infant Only, Object Only*). It is plausible that, at 12 months of age, infants have come to expect the social partner to behave in a certain way in triadic interactions and are perturbed by ambiguous situations. Prior research has revealed that infants this age have difficulties interpreting actor-object actions that are ambiguous (e.g., Woodward & Sommerville, 2000). Thus, even 12-month-olds' object processing within the triadic interaction seems affected by the adult's behavior, albeit less strikingly than 9-month-olds' behavior. Future investigations should attend to the factors—both social and task-related—that determine what does and does not enable triadic interaction to facilitate object processing in 12-month-old infants.

Experiment 1 revealed that compared to a non-social context (*No Social Partner*), a naturalistic triadic interaction between infant, object, and adult (*Joint Attention*) was adversely affecting 9-month-olds' object processing. How can this result be reconciled with previous results suggesting that engaging infants in joint attention versus non-joint attention interactions enhances attentional processes and facilitates information processing (Reid & Striano, 2005; Reid et al., 2004; Striano et al., in press)? As mentioned earlier, these studies differ from the current study on methodological as well as theoretical grounds. For example, while Striano and her colleagues examined 9-month-olds' object processing within the first few hundred milliseconds following a short joint or non-joint attention interaction (i.e., eye gaze cueing or attention-getting aspects within joint and non-joint attention contexts), the current study examined infants cumulative novelty responses across two test trials. Further, while previous studies did not specify the time infants need to look at the familiarization object, all infants in the current study were required to accumulate 20 s of total looking time before proceeding to the test phase. Moreover, whereas the social partner looked at the infant only once and then immediately to the object (i.e., one joint attention look prior to test phase) in earlier studies, the adult exchanged many joint attention looks during the prolonged familiarization phase of the current study. Additionaly, whereas either the object or both object and social partner were presented on a computer screen in former studies, every part of the triadic interaction was live in the present study. Thus, measuring cumulative novelty responses, the accumulated looking requirement, the prolonged familiarization phase with its many joint attention bouts, or the live characteristic of the social interaction might have contributed to the differences in results compared to earlier studies. In general, it can be said that visual object-processing is affected by the nature of the social partner's engagement with the infant and object. While not directly comparable, the results of the current study are in agreement with the findings of Miceli et al. (1998) and Itakura (2001), in that all three studies suggest that infants' perceptual object processing is influenced by the social-interactinal factors prevailing in triadic interactions between self, other, and object.

In the real world, objects are very seldom processed devoid of any context. We often engage with and learn about objects within social interactions. The current study was an initial attempt to examine which social-interactional factors within live triadic settings facilitate or impede infants' processing of physical stimuli. The results revealed that processing and learning about objects within a social context does not take place in a vacuum, but is sensitive to the social-interactional factors that prevail. The mechanisms that underlie the interaction between social context and object processing as well as developmental changes merit investigation in future research.

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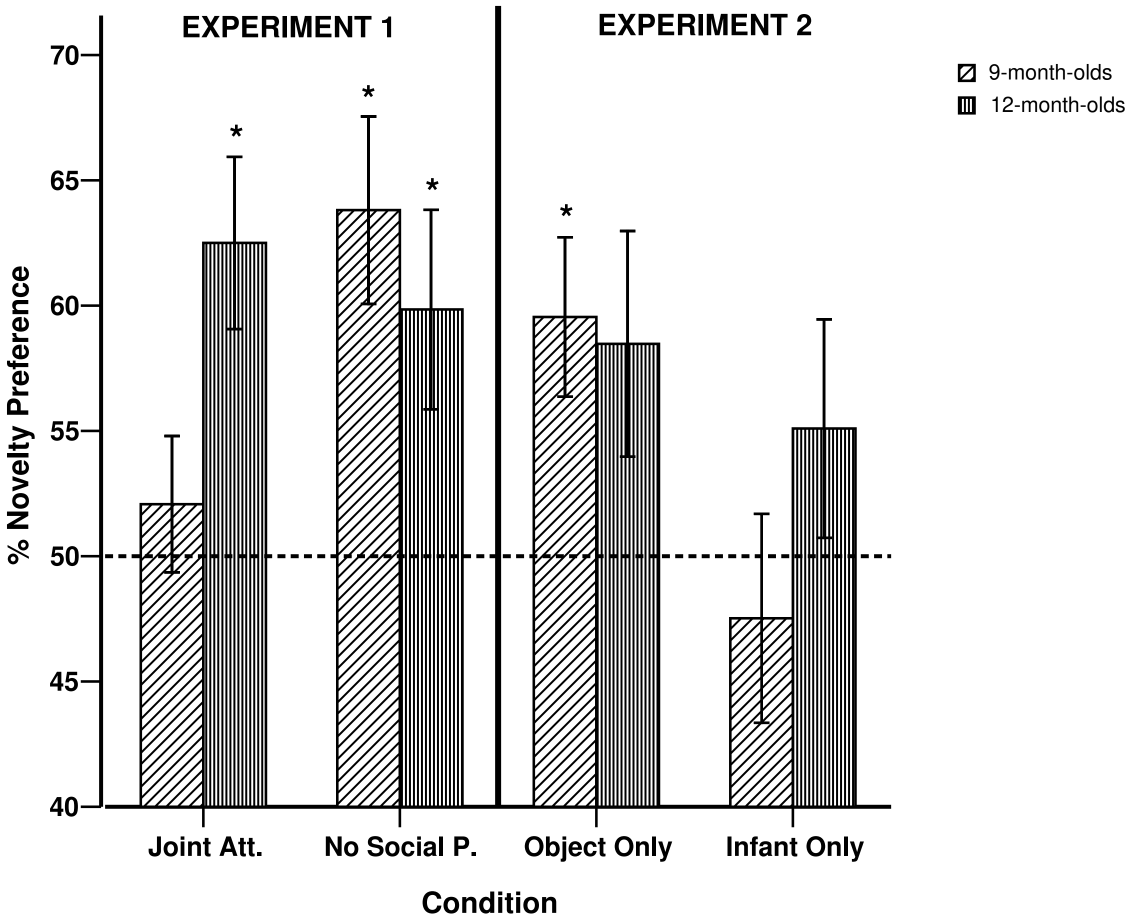
Footnotes

[1] In removing the social partner during test trials we followed the procedure that Hood, Willen, & Driver (1998; Experiment 2; see also, Reid & Striano, 2005) used with younger infants. These authors found that extinguishing the central face during test trials facilitated orienting and shifting of infants' attention to peripheral probes. Although attentional latencies from a central to a peripheral stimulus decrease with age (e.g., Hood & Atkinson, 1994), by removing the social partner during the test phase we circumvented the problem of infants' tendency to fixate on salient central stimuli. This provided infants with a situation where they could fully display their object processing capacities because they did not have to disengaging from an interesting central stimulus to visually compare the novel and familiar objects.

[2]When we only examined 9-month-olds who sampled both test objects during the first test trial of the *Joint Attention* condition (n = 13), we found their initial visual preference to be indicative of a novelty response (M = 59.99, SE = 4.16). However, given that the procedure employed in the current study dictates consideration of both tests trials, this issue is not considered further here.

Figure Captions

Figure 1. Nine- and 12-month-olds' mean percentage novelty preference (and Standard Error) during test trials in the Joint Attention and No Social Partner condition (Experiment 1) and the Object Only and Infant Only condition (Experiment 2).



* = Novelty preference significantly above the 50% chance level.